U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
NATIONAL METEOROLOGICAL CENTER

OFFICE NOTE 275

Zonal Mean Temperature Forecasts By the NMC Global Spectral Model

Joseph P. Gerrity, Jr.
Development Division

April 1983

ACKNOWLEDGEMENTS

The data used in this investigation were made available through the efforts of J. Sela and M. Rozwodoski. Their assistance is gratefully acknowledged.

1.0 Introduction

Beginning with data for September 1981, a systematic verification program has been run by Mark Rozwodoski to diagnose, on a monthly basis, the zonal average, temperature forecast errors committed by the NMC, large-scale prediction model. The operational analysis (Hough) is used as a reference. The mean and stardard deviation statistics are computed for the twelve mandatory pressures (1000 - 50 mb) for forecasts of length 24, 48, 60, and 72 hours. For the longer range forecasts (out to 192 hours), only four pressure levels are verified, viz: 1000, 850, 500, and 250 mbs. In addition, to the forecast statistics, the mean and standard deviation of the verifying (monthly mean) analysis is also computed.

The data collected through January 1983 have been analyzed with a view to defining the deficiencies of the forecast model, especially those related to the omission of a scheme for the parameterization of radiative heat transfer. Also detected in the analysis was the impact of varying the forecast model resolution, and an apparent problem in the operational analysis stratospheric temperatures.

At the beginning of the period for which data has been analyzed, the prediction model was run with 12 levels of vertical resolution only to 84 hours. After May 1982, the vertical resolution was kept at 12 levels through 144 hours. When the vertical resolution was reduced, the model had only six levels of resolution. The distribution of the vertical resolution may be seen in Figure 3.

After 48 hours, the forecast model's horizontal resolution is reduced to rhomboidial 24 truncation. The forecasts are postprocessed prior to verification using a 2.5 degree latitude/longitude grid.

Relatively few changes were made to the prediction model during the period. Among the more significant changes we may note the following:

1.) August 1982 Revision of precipitation scheme.

2.) September 1982 Tendency method used.

3.) October 1982 Analyzed sea surface temperature used.

2.0 Distribution of Land and Sea

In order to relate the zonal average temperature forecast errors to their potential causes, it is instructive to note the model's distribution of land and sea.

Figure 1 displays the fraction of the model's Gaussian grid-points which the model interprets to be occupied by an ocean surface. It may be noted that the Arctic is regarded as a land, i.e., ice, surface. South of 30°N, there are more ocean points than land points. North of 60°N, the oceans occupy less than one-fifth of the area.

Figure 2 shows the zonal average height of the model ground surface above mean sea-level. The maximum height is just under 600 m. Except near the North Pole, the zonal mean height of the ground is more than 100 m above m.s.l.

3. Verifying Analyses

The operational objective analysis, produced using the Hough function technique, was used in the verification of the forecasts. This analysis system uses first guess fields provided by the NMC Data Assimilation System (DAS). During August 1982 the DAS was modified to employ a multi-variate, optimum interpolation (OI) scheme to update forecasts produced by a 12 layer, 30 mode version of the spectral model. Previously a univariate OI analysis method was used to update a 12 layer, 24 mode version of the spectral model.

As part of the verification package, Rozwodoski accumulated the monthly average, zonal mean temperature analysis and the standard deviation of the analysis temperature about the mean. Examples of these analyses, for June and December 1982, are shown in Figures 4 through 7. It is of interest to note that the standard deviation charts show a secondary maximum in middle-latitudes which migrates from near 40°N to 50°N from June to December. The polar maxima in standard deviation are in part due to the smaller area represented by the polar latitude belts. The magnitude of the wintertime standard deviation near 85°N at levels above 400 mb does seem to be rather large.

We were able to compare the NMC analysis with mean zonal temperatures for June and December compiled by Oort and Rasmusson (1971). The differences between their average cross sections and those obtained by the NMC analysis in December and June 1982 are given in Figures 8 and 9.

Throughout most of the troposphere the NMC analysis are warmer than the Oort and Rasmusson climate values. Much more difficult to overlook are the differences found in the stratosphere. In both June and December the NMC analysis at 50 mb appears to be significantly colder than the analysis values given by Oort and Rasmusson. In the vicinity of the tropical troposphere near 100 mb the NMC analysis is significantly warmer than the Oort and Rasmusson analysis. Perhaps the tropopause inversion is smoothed out by the use of only mandatory level data in the Hough analysis.

4. 72 Hour forecast temperature verification

Because the verification of all twelve mandatory pressure levels was done only through 72 hours, we concentrated upon the analysis of forecast error at that time range. In Figure 10 the average error over the northern hemisphere is shown for each month and each vertical level for the seventeen months of data available at the time of this study.

Several points may be noted in this diagram. We notice first of all that there is present some interannual variability. On the whole the forecast error in mid-troposphere was somewhat larger in the winter of 82-83 than in the winter of 81-82. On the whole the stratosphere is predicted to be too cold, as is the region near the ground.

The intra-annual variation in the error through the troposphere supports the hypothesis that the systematic error is due, in good part, to the absence of a parameterization of radiative heat tranfer. The stratospheric error (too cold) would only be aggrevated by the introduction of radiative cooling, however, unless some non-linear effects can be invoked.

In passing it is evident that the analysis' deviation from Oort and Rasmusson's mean field, noted in section 3, is not reflected in the forecast error field. This suggests that the NMC analysis of the stratosphere may be being determined more by the model used to assimilate data than is desirable.

In Figure 11 we show the 72 hour forecast error in the zonal mean, 1000-500 mb thickness which was computed from the 1000, 850, 700 and 500 mb temperature errors. This chart shows that the lower troposphere is predicted to be too warm except in the Summer and in the tropics where it tends to be somewhat too cold. Throughout all seasons the sense of the error is to reduce the westerly thermal wind which should tend to inhibit baroclinic cyclogenesis.

In Figures 12 through 28, vertical sections of the monthly average, zonal mean temperature error is shown for the seventeen months studied. The excessive warmth of the troposphere is anchored to a polar maximum whose intensity waxes in Winter and wanes in Summer. The cold bias at low levels in the tropics and in the stratosphere is evident in all months.

We note the very large cold error at the 70 - 50 mb level over the Pole in Winter, and the northward movement of the low level cold bias that takes place as Summer approaches.

5. Error Growth

Although the verification data for all twelve mandatory levels was restricted to the first 72 hours, we do have access to statistics for 850, 500, and 250 mb through 192 hours. In Figures 29 through 40, the monthly average, zonal mean temperature error (bias) is shown for each 24 hours at three latitudes (10, 40, and 70°N). All four seasons are represented by the months of March, June, September and December, all in 1982.

At 850 mbs, it is noteworthy that the error at 40°N is quite small in all seasons through eight days. Except for the Summer season (June) the northerly temperatures (70°N) are marked by a systematic growth in excessive warmth. At low latitudes (10°N) there is a systematic cooling evident but it appears to be quite small (2°/8 days).

The distribution of land and sea with latitude (see Figure 1) may explain why the omission of radiation has such a relatively small impact on the 850 mb zonal mean temperature error except at the polar latitudes. Only in the polar zone are we dealing with a continental zone where radiative effects should play a dominant and relatively one-sided role in the medium range forecasts. At the other latitudes, there is room for off-setting errors to occur over ocean and continent producing relatively small zonal mean errors. This point is suggested by Karl Johannessen's investigations of the global distribution of monthly mean error.

Turning attention to the 500 mb level we see that the mid-latitude and polar regions march together in the growth of a warm bias in three of the four seasons. In Summer, the errors in all three latitudes are quite small at 500 mbs. Removed from the strong influence of the surface transfers, we observe here systematic evidence for the need to include radiative cooling into the model, at least over continental, extra-tropical areas.

At 250 mbs, the temperature error is quite small until the time when the vertical resolution of the model is changed from twelve to six layers. This time was changed from 84 to 144 hours in May 1982. It would appear to be difficult to improve on the level of the systematic error achieved by the model at the 250 mb level.

6. Conclusions

The use of zonal mean statistics provides a relatively compact data set for investigating the performance of an atmospheric prediction model. The interpretation of the data must be done with care however and requires cross validation by other methods of analysis.

Our initial objective was to determine the empirical evidence indicating the gravity of omitting radiative heat transfer in the global spectral model. It is well-known that the comprehensive treatment of radiative processes is a very costly appendage to a prediction model, therefore we felt it recessary to establish the magnitude of the errors incurred by neglecting the process.

It is our conclusion that serious errors are evident in the low and mid-troposphere especially in the polar regions. These errors are of a type that might be readily attributed to the omission of the radiative process. In the tropics and in the stratosphere, however we do not find the sort of errors that can be directly attributed to the omission of radiation.

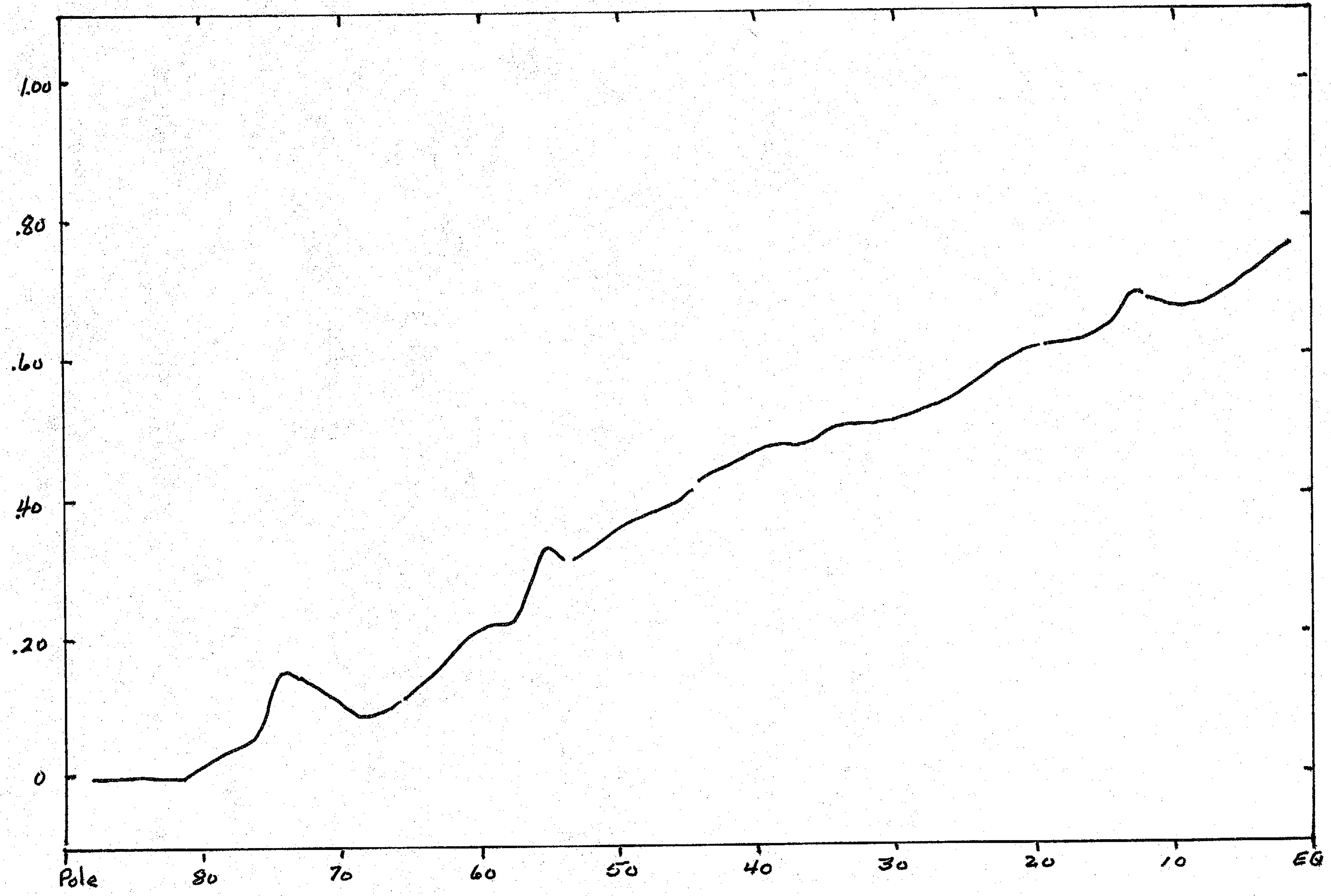
There is a strong suggestion that sensible and latent heating of the tropics is being significantly under-estimated by the parameterization methods used in the prediction model. The addition of radiation processes to the model will almost surely cause the model to be even colder in the tropics than it is now. Therefore we believe that proper results can be achieved only by pursuing a comprehensive approach to the treatment of radiation with other processes such as convection.

The stratosphere offers another dilemma; since it is already too cold and net radiative effects should act to cool it further, we are unable to recommend incorporation of radiation as a cure to the weak symptoms manifested in these stratospheric layers of the model. It is possible that the rather poor vertical resolution of the model stratosphere leads it to have relatively weak meridonial heat transfers thereby negating the need for radiative cooling. This is a complex question which must be comprehensively addressed if it is to be treated properly.

Thus our investigation leads us to believe that only a very limited introduction of radiative effects may be justified in the short term. I think we may find it to be possible to improve performance in the polar regions by introducing a cooling process into the low and mid-troposphere to simulate some aspects of the radiation process. Some work along this line has been undertaken. We conclude that a more comprehensive treatment of radiation should be pursued in conjunction with efforts to improve the entire physics parameterization system of the model. This effort is certainly required for our efforts to extend the model forecasts into the medium-range.

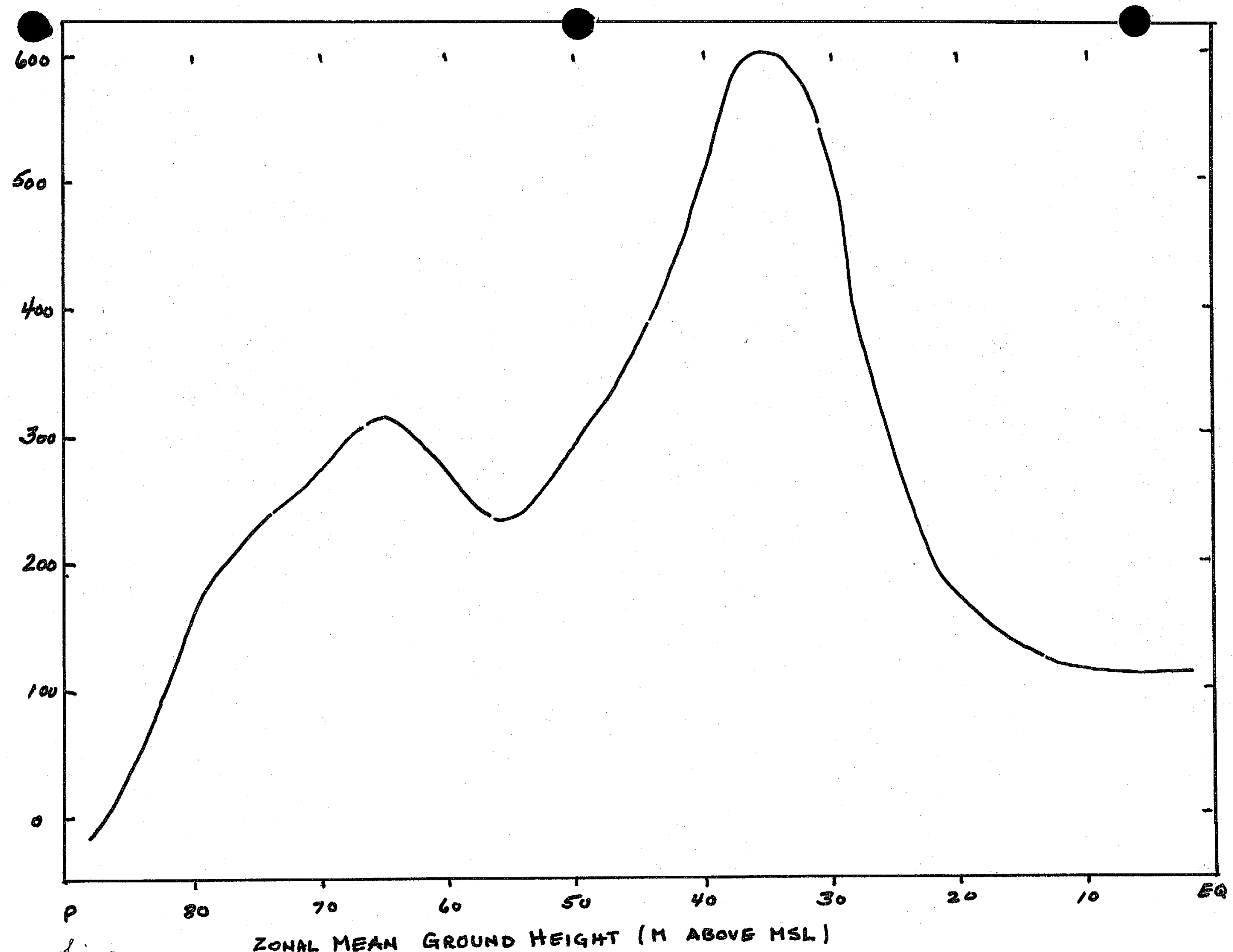
7. References

Oort, A.H., and E.M. Rasmusson, 1971: "Atmospheric Circulation Statistics" NOAA Professional Paper 5, NOAA, DOC, Rockville, MD, 323 pp.



FRACTION OF OCEAN POINTS ON LATITUDE CIRCLE

Fig 1.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EQ
ZONAL MEAN GROUND HEIGHT (M ABOVE MSL)

Fig 2.

MODEL STRUCTURE

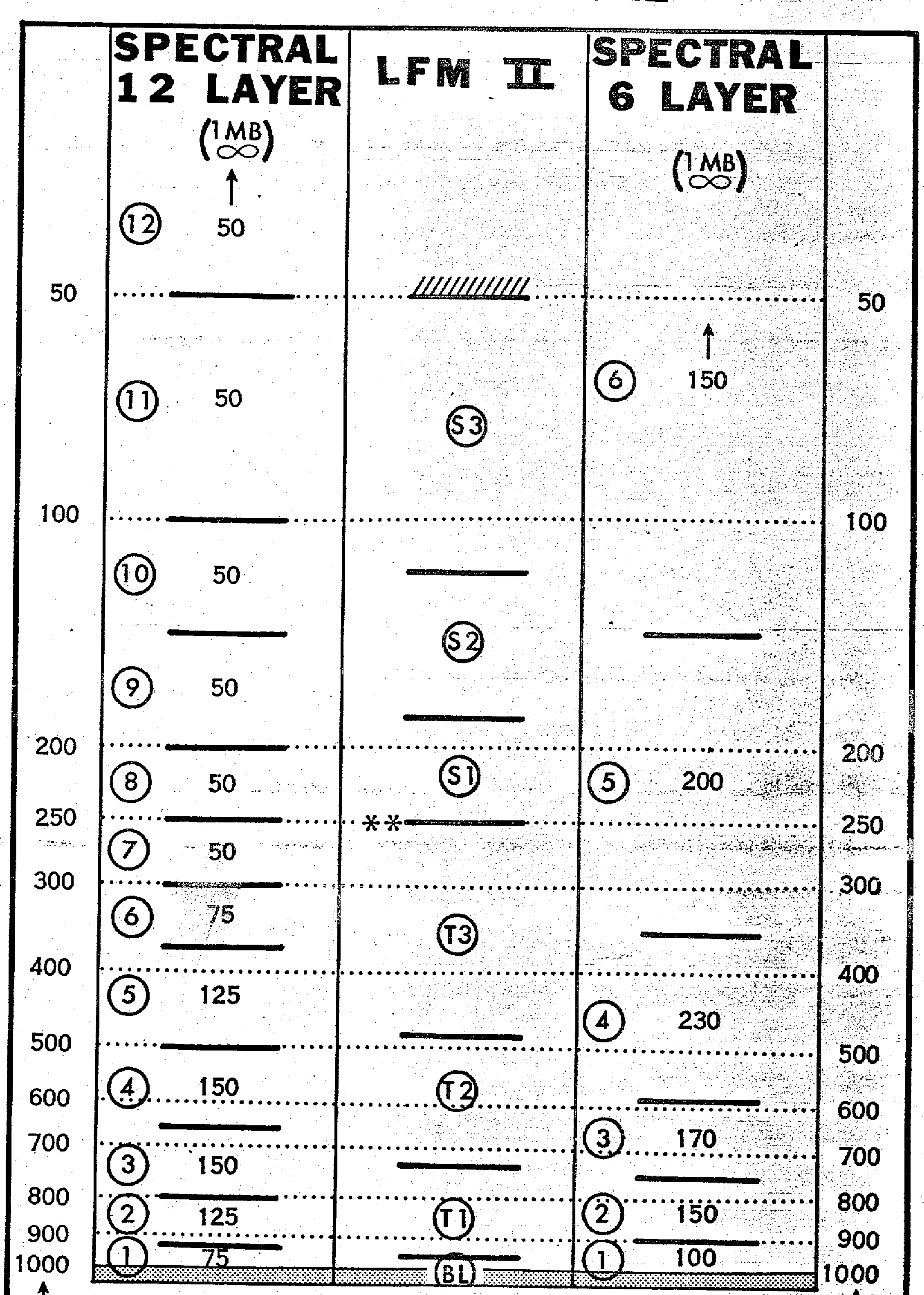
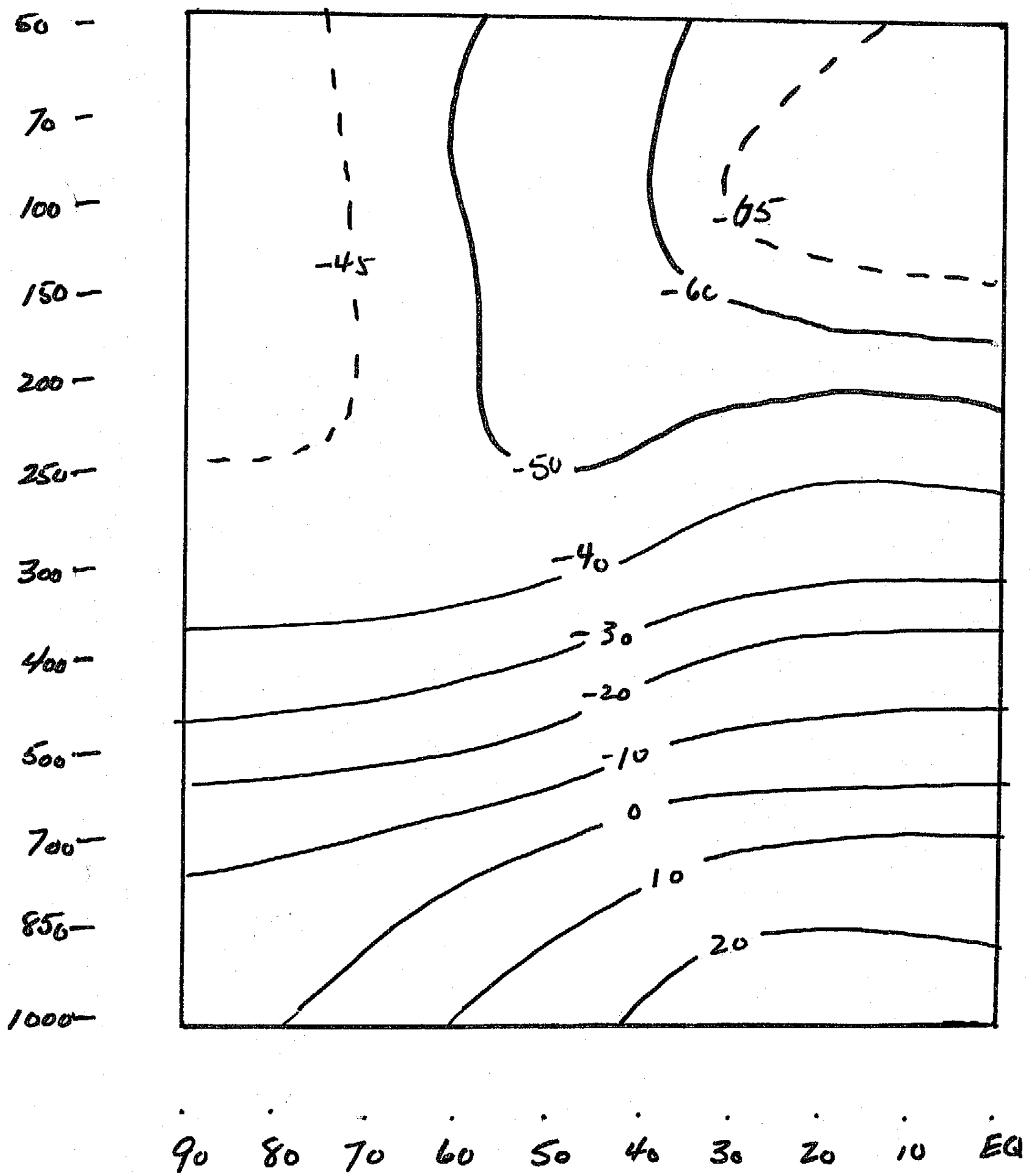


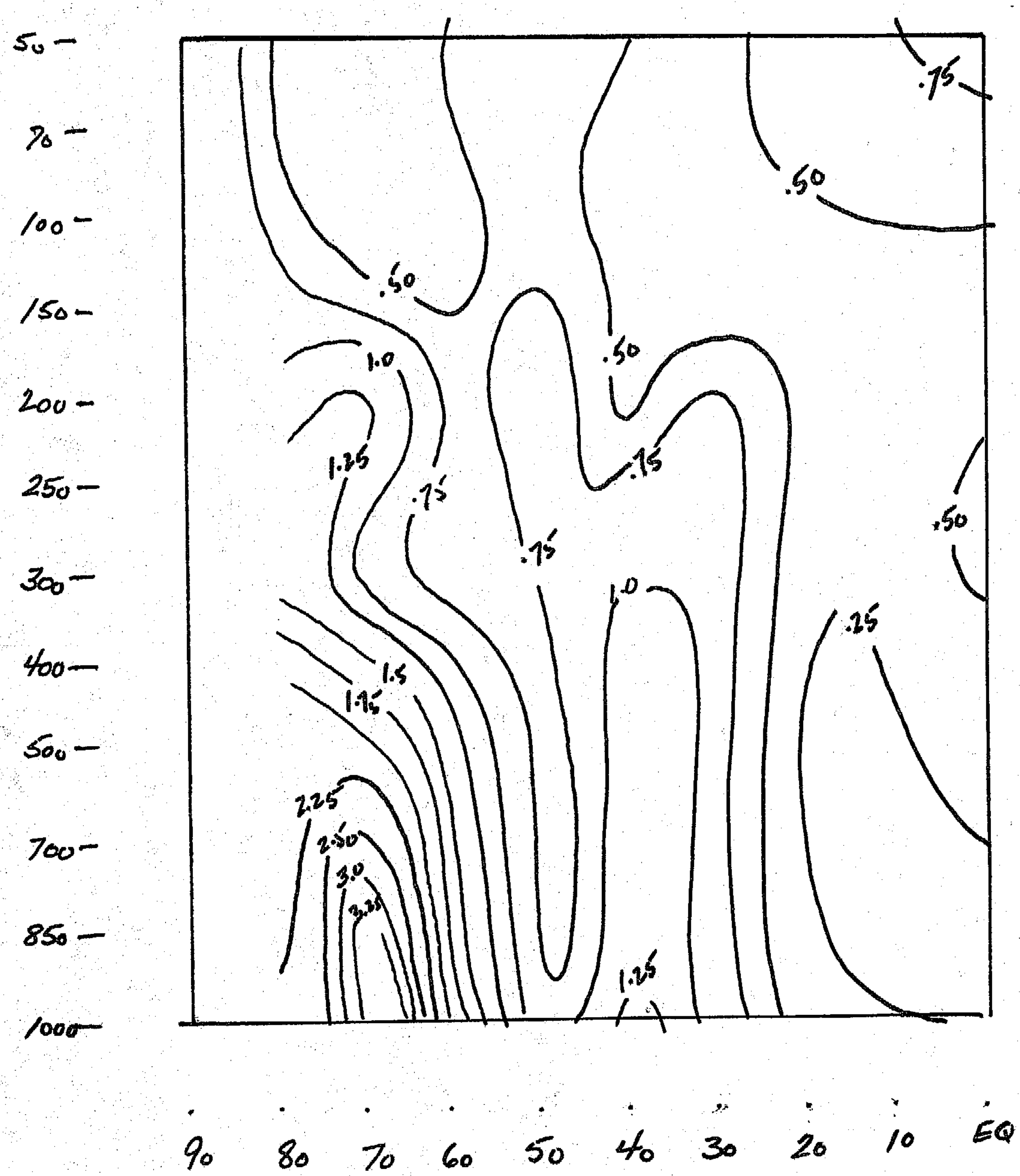
FIGURE 3



JUNE '82

NMC
ANALYSIS
ZONAL
MEAN
TEMPERATURE

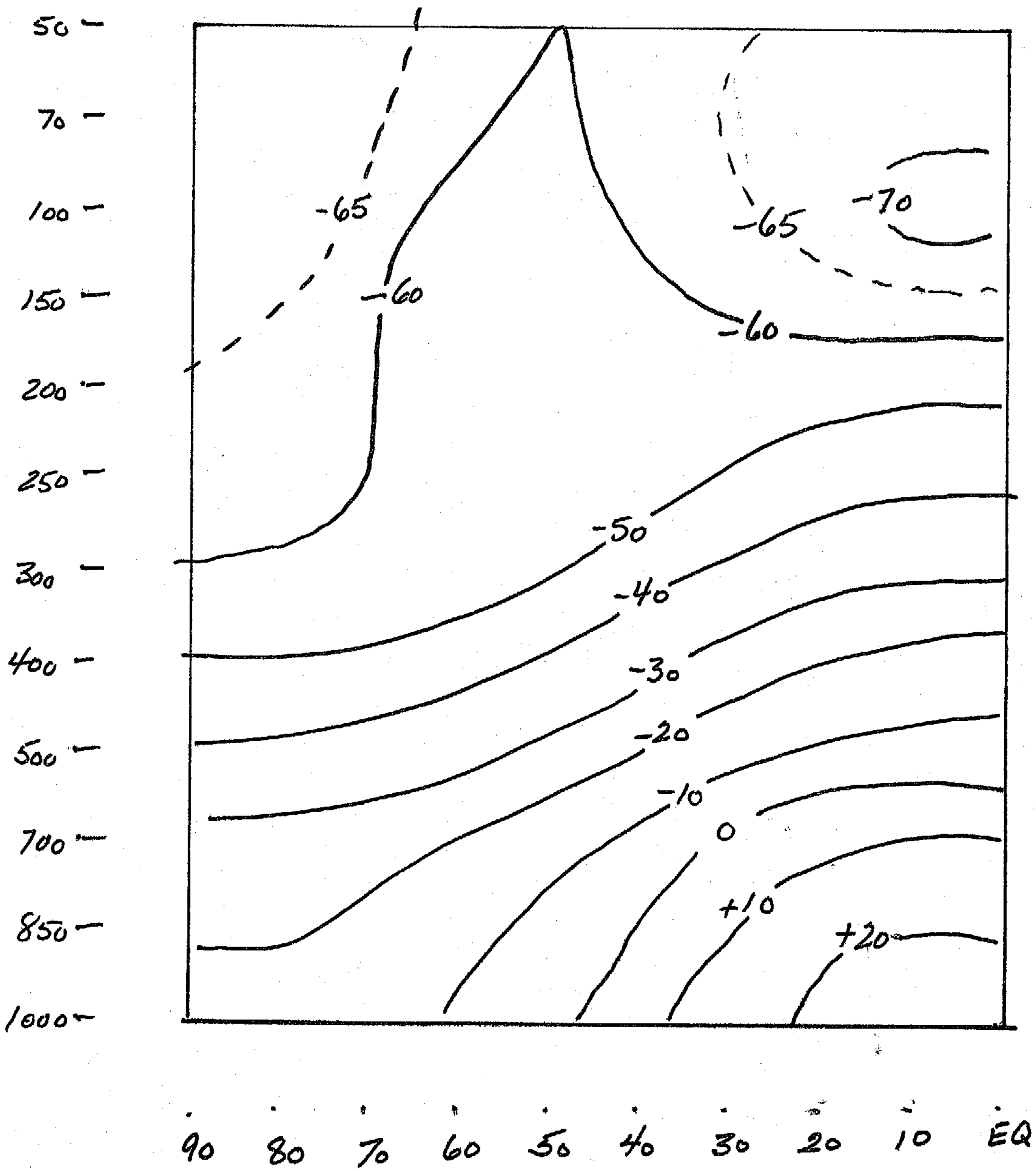
Fig 4



JUNE '82

STANDARD DEVIATION ANALYSIS TEMPERATURE

Fig 5



DEC '82

NMC

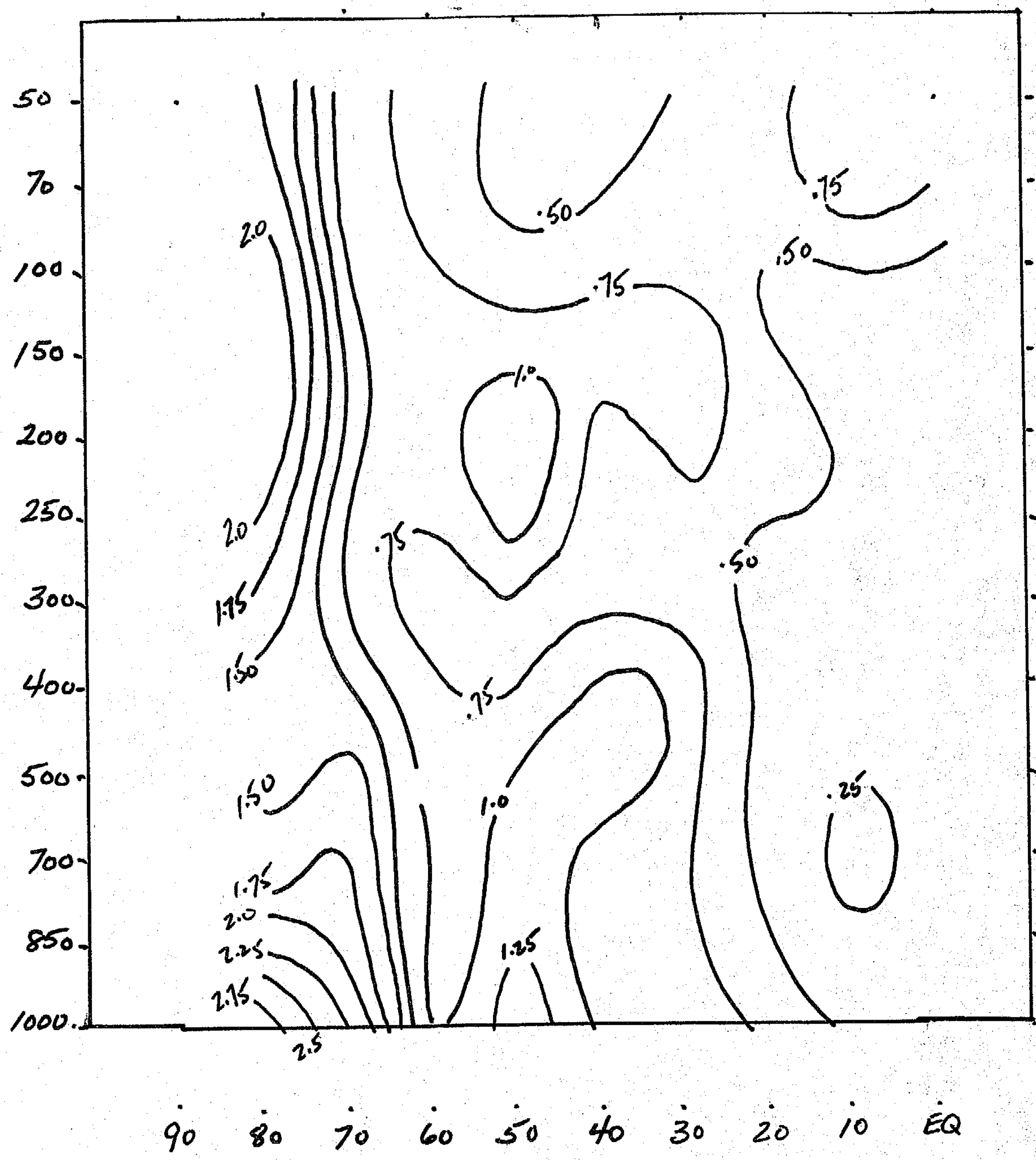
ANALYSIS

ZONAL

MEAN

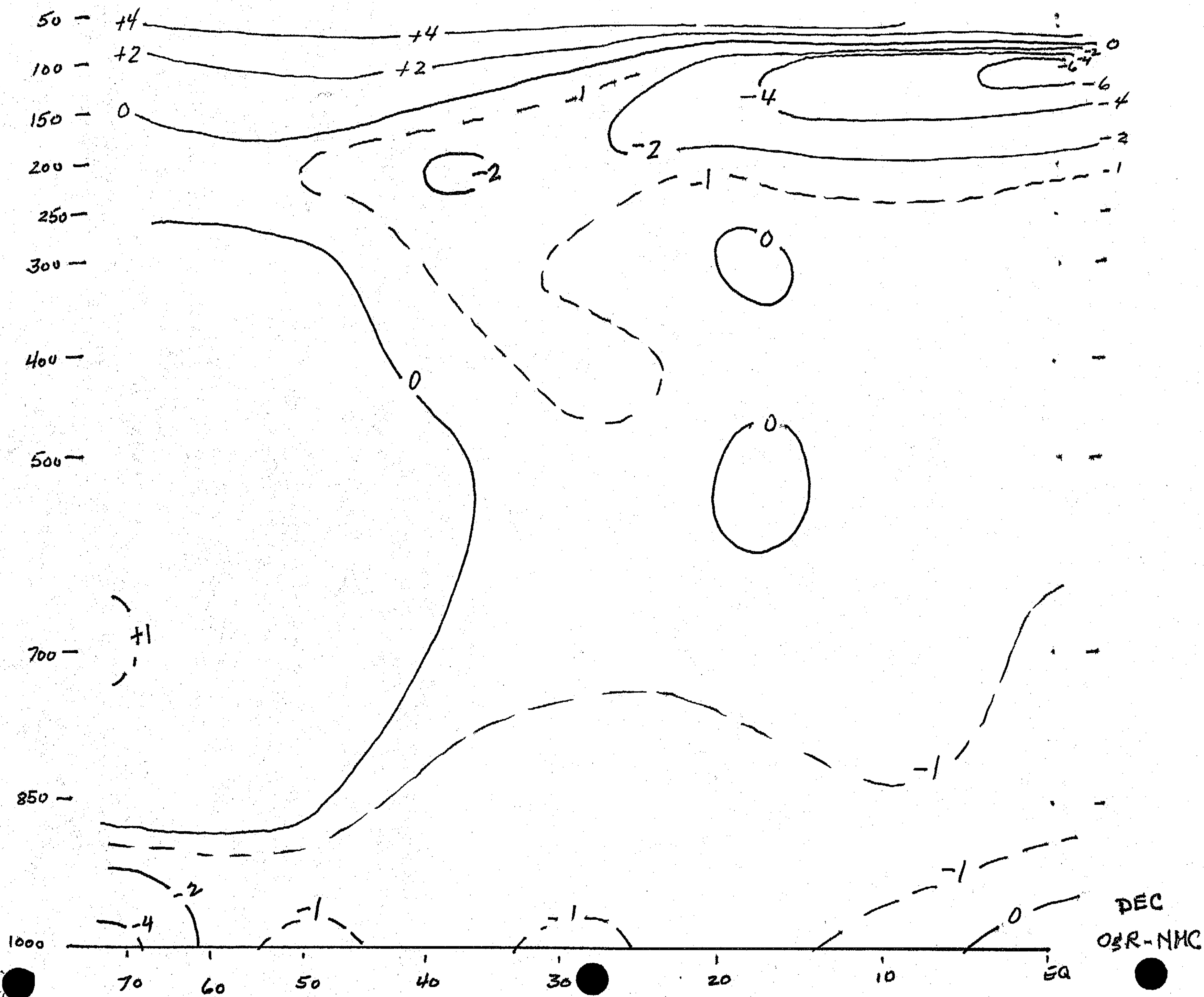
TEMPERATURE

Fig 6



DEC '82
STANDARD
DEVIATION
ANALYSIS
TEMPERATURE

Fig 7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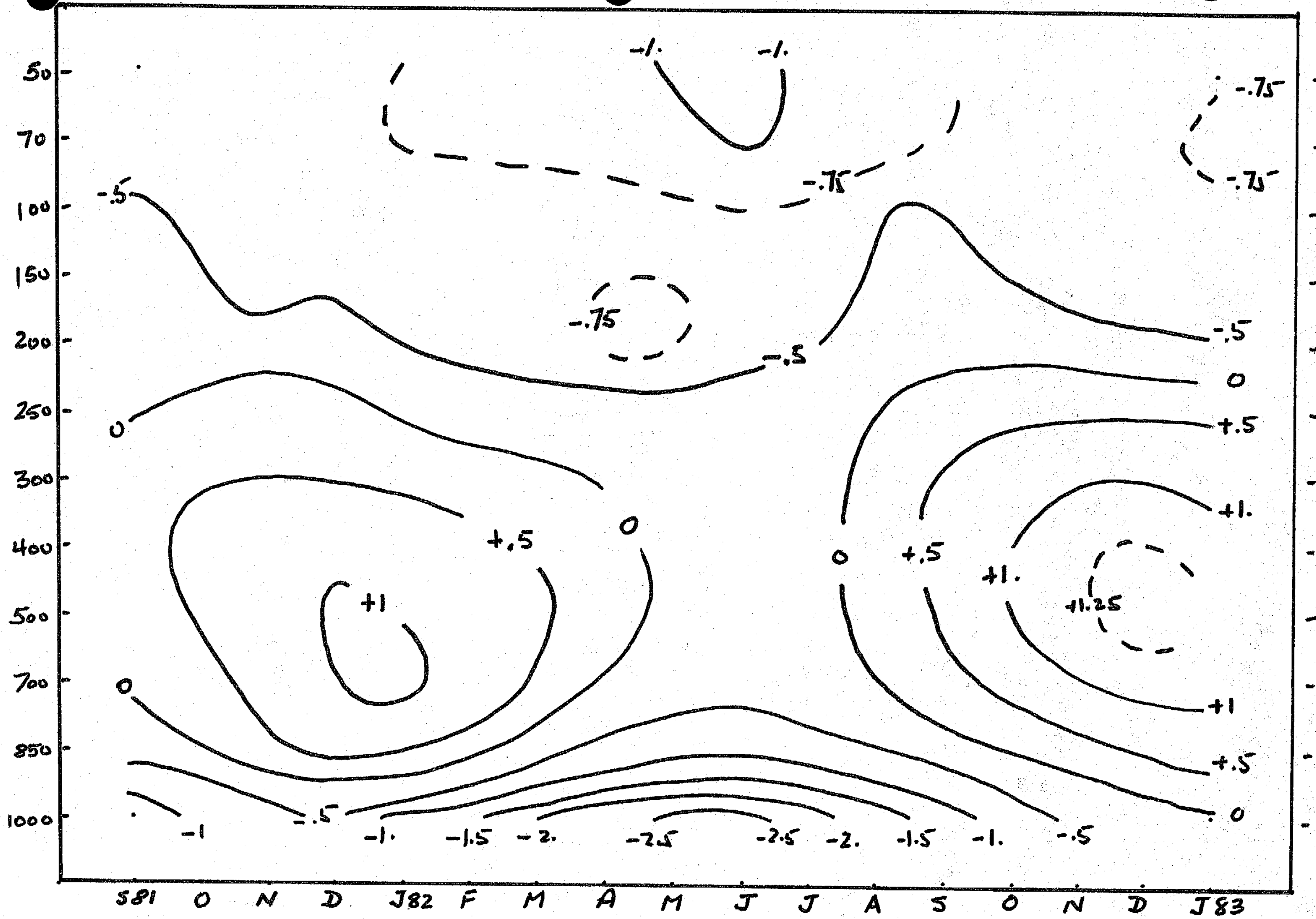
DEC
OgR-NMC

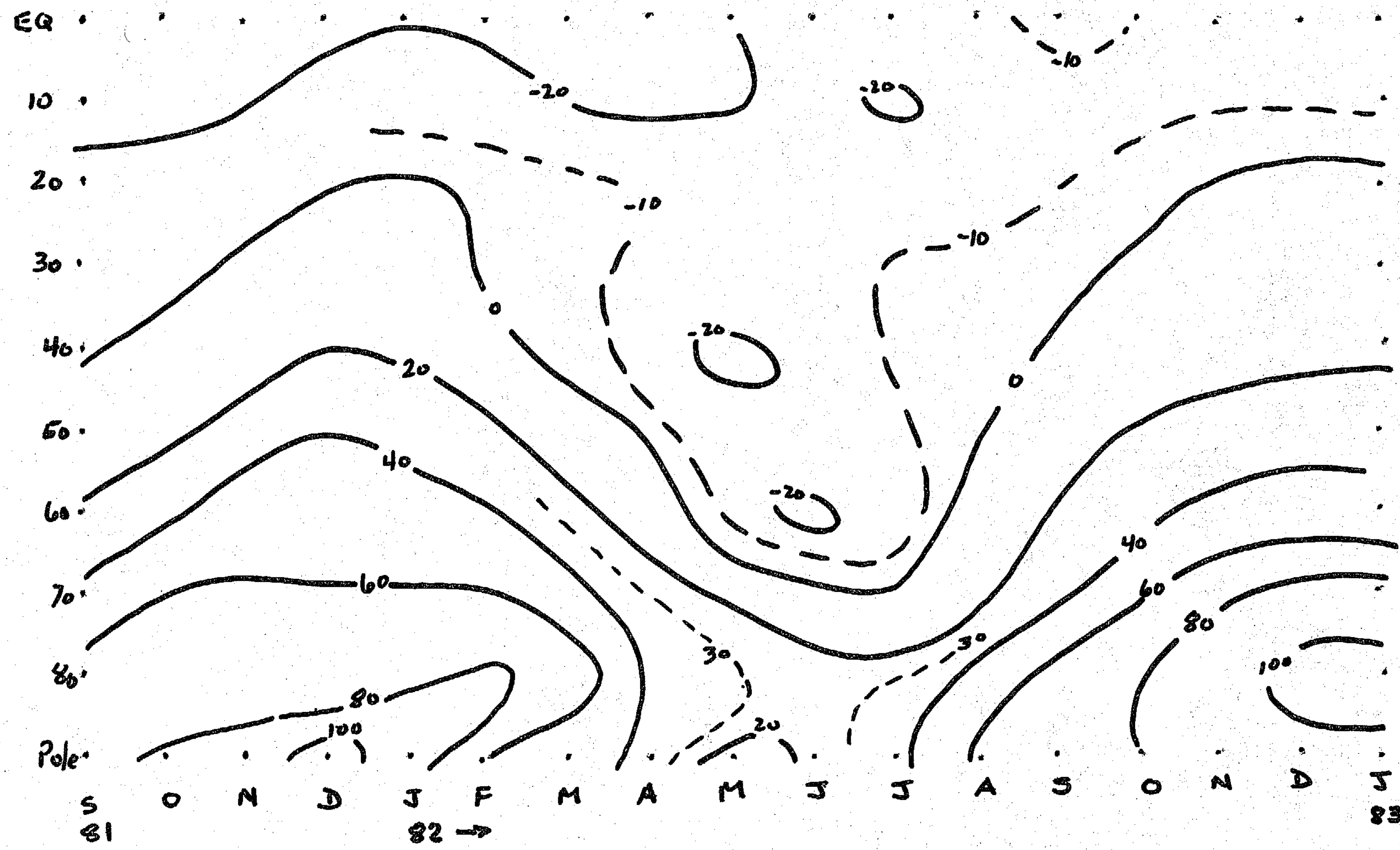
JUNE
OSR-NMC

Fig 9



MEAN TEMP ERROR 72 HR FCST SEP 81 TO JAN 83

Fig 10



72 HR FCST ERROR 1000-500 MB THICKNESS (m)

Fig 11

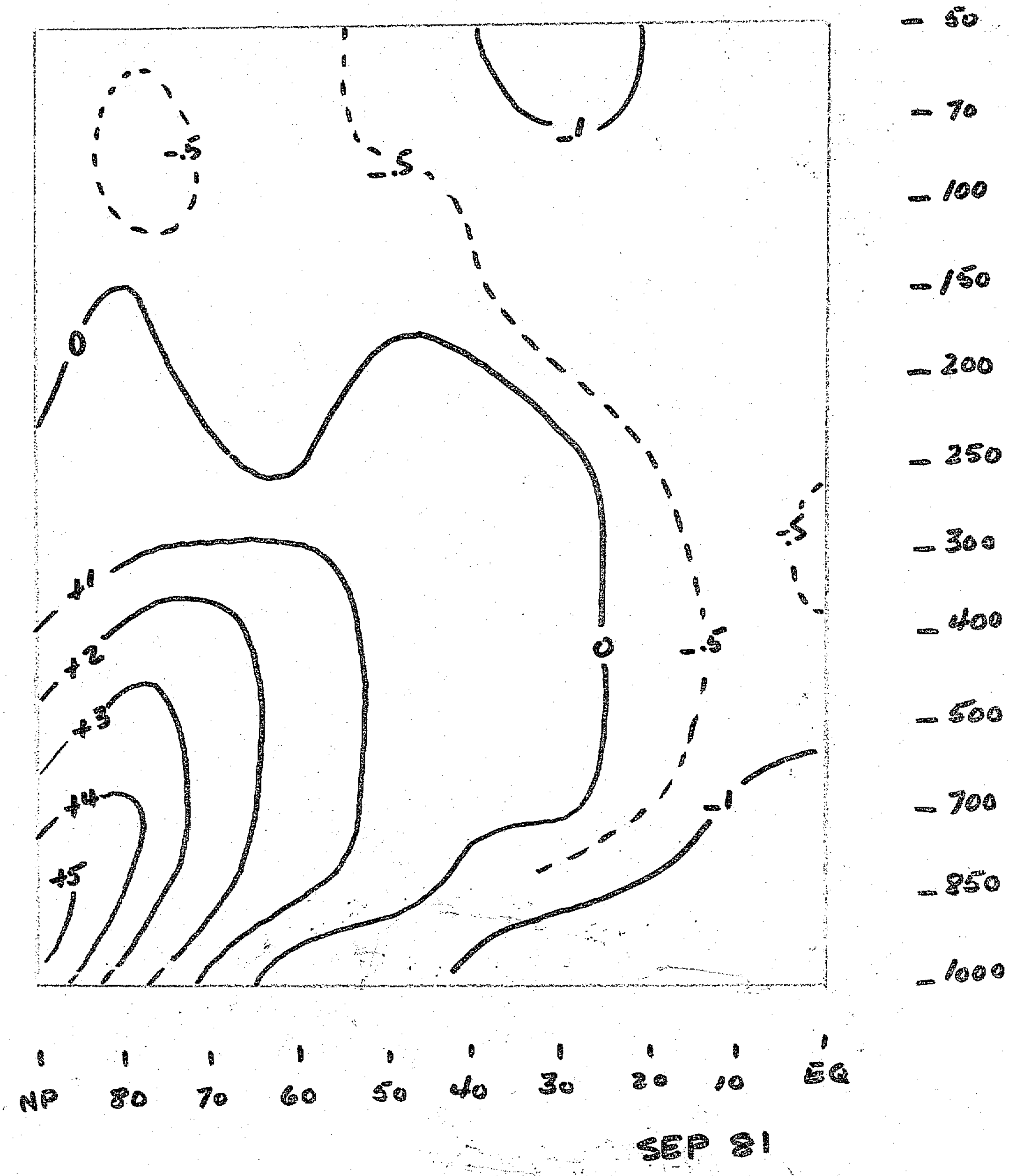


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fig 12

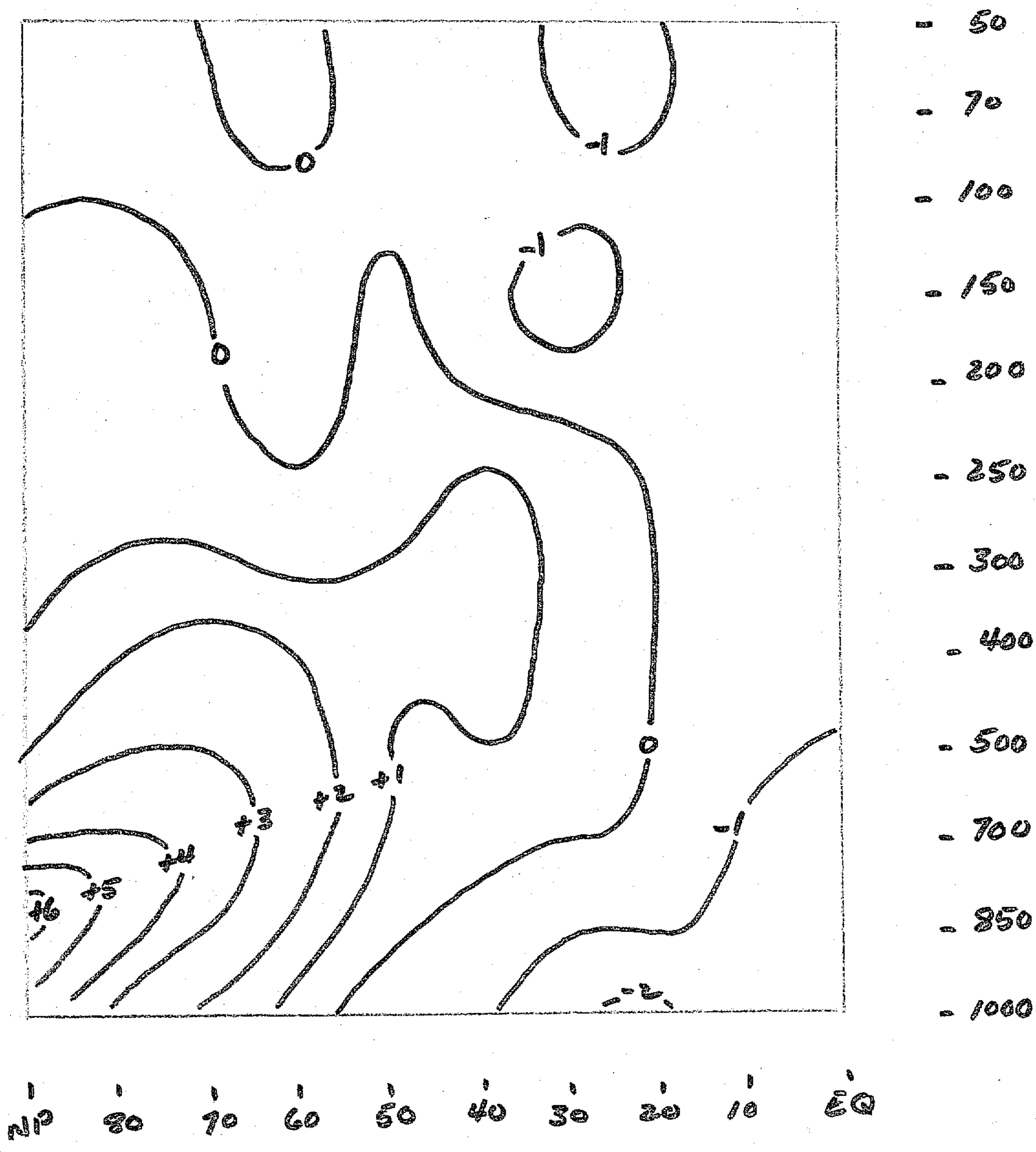

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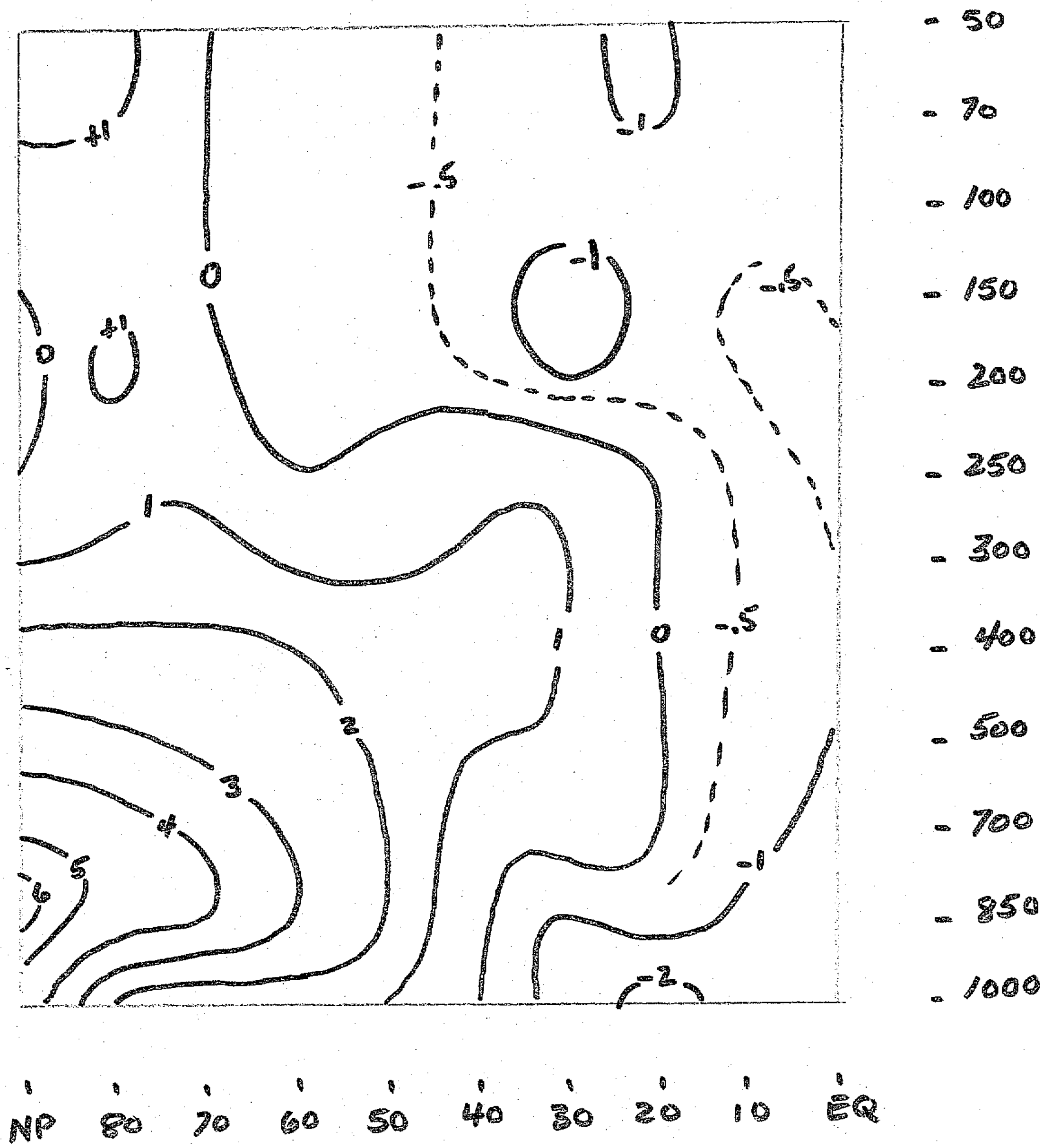
Fig 13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Nov 81

Fig 14

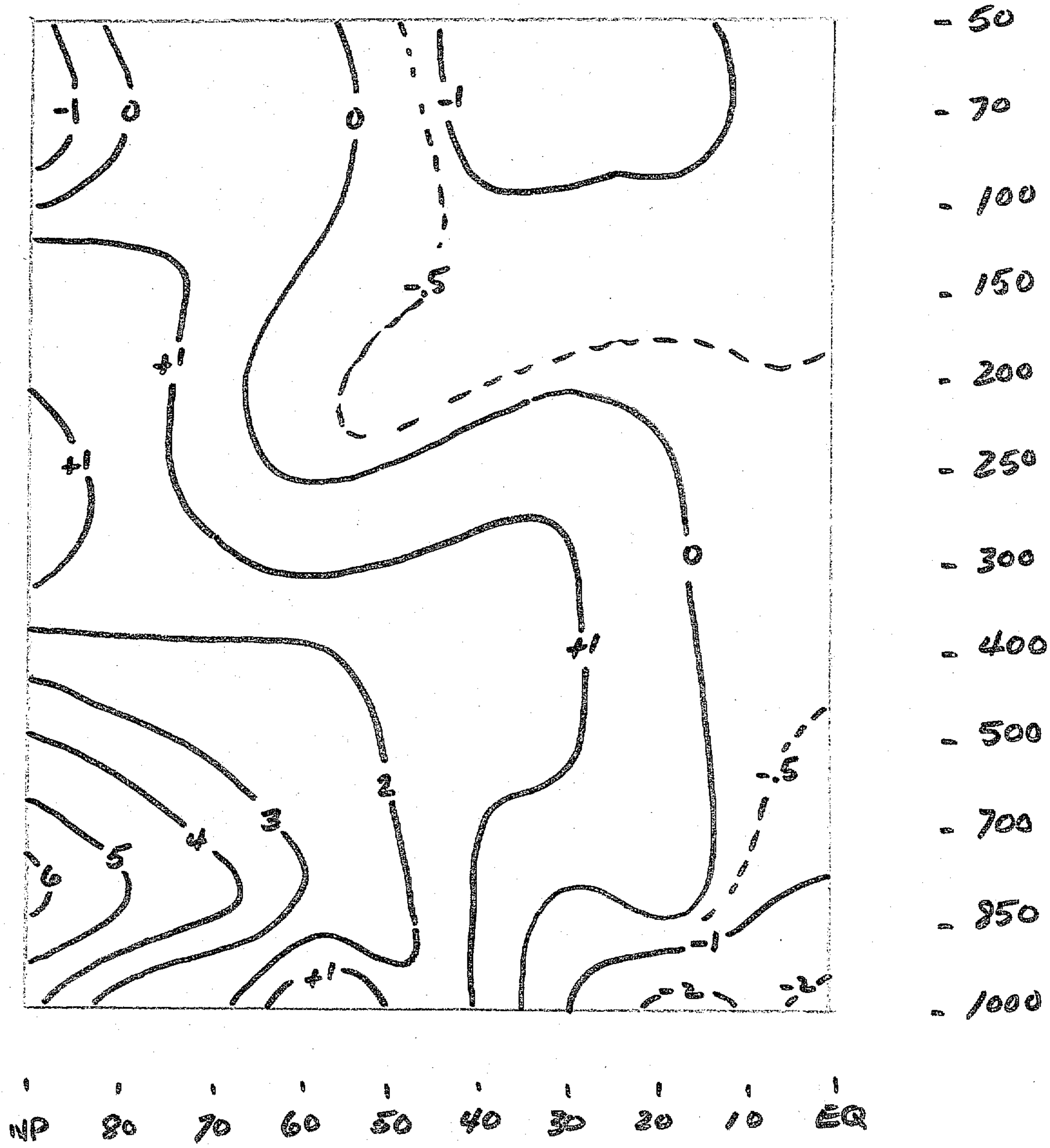

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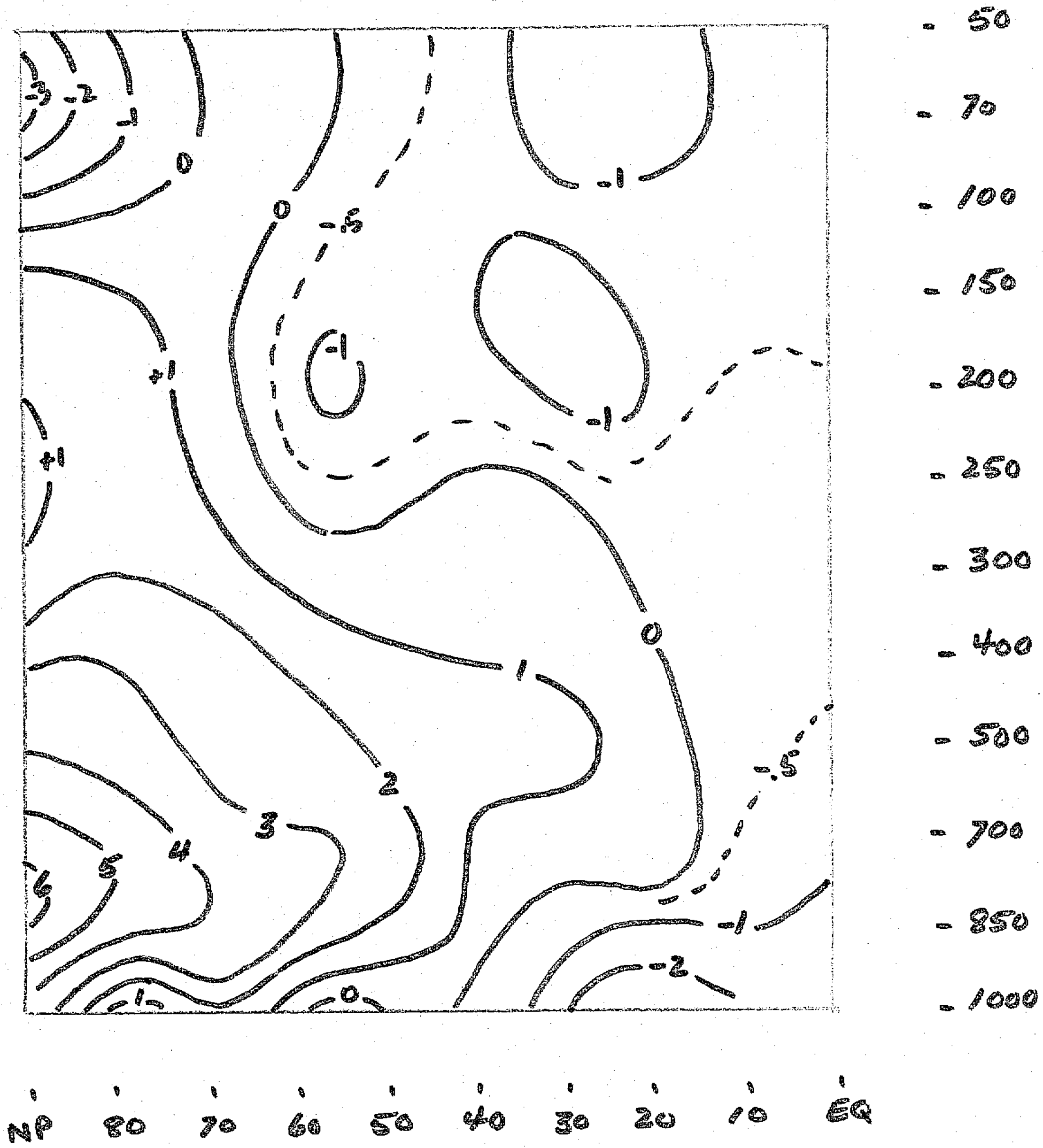
Fig 15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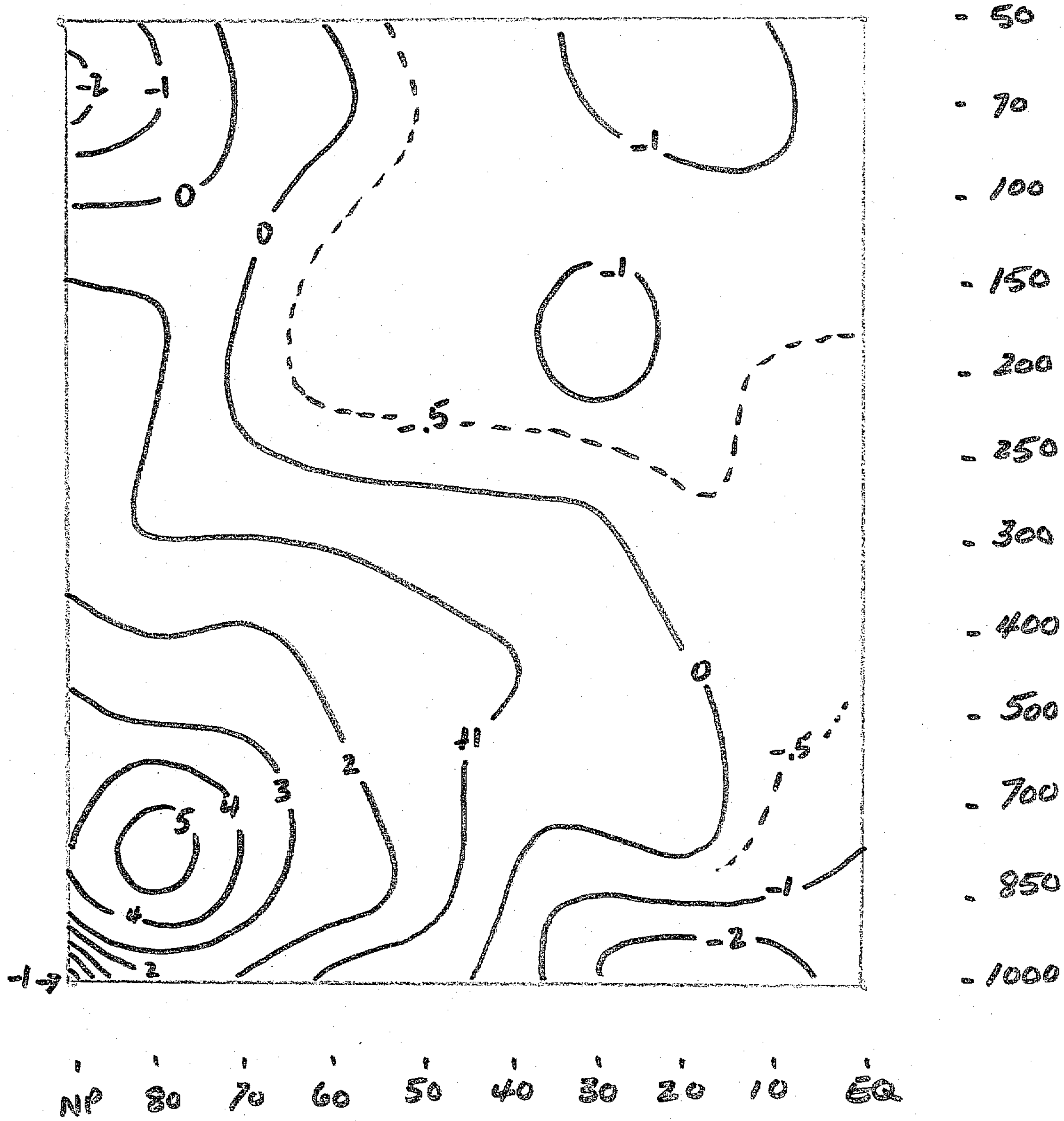
JAN 82

fig 16



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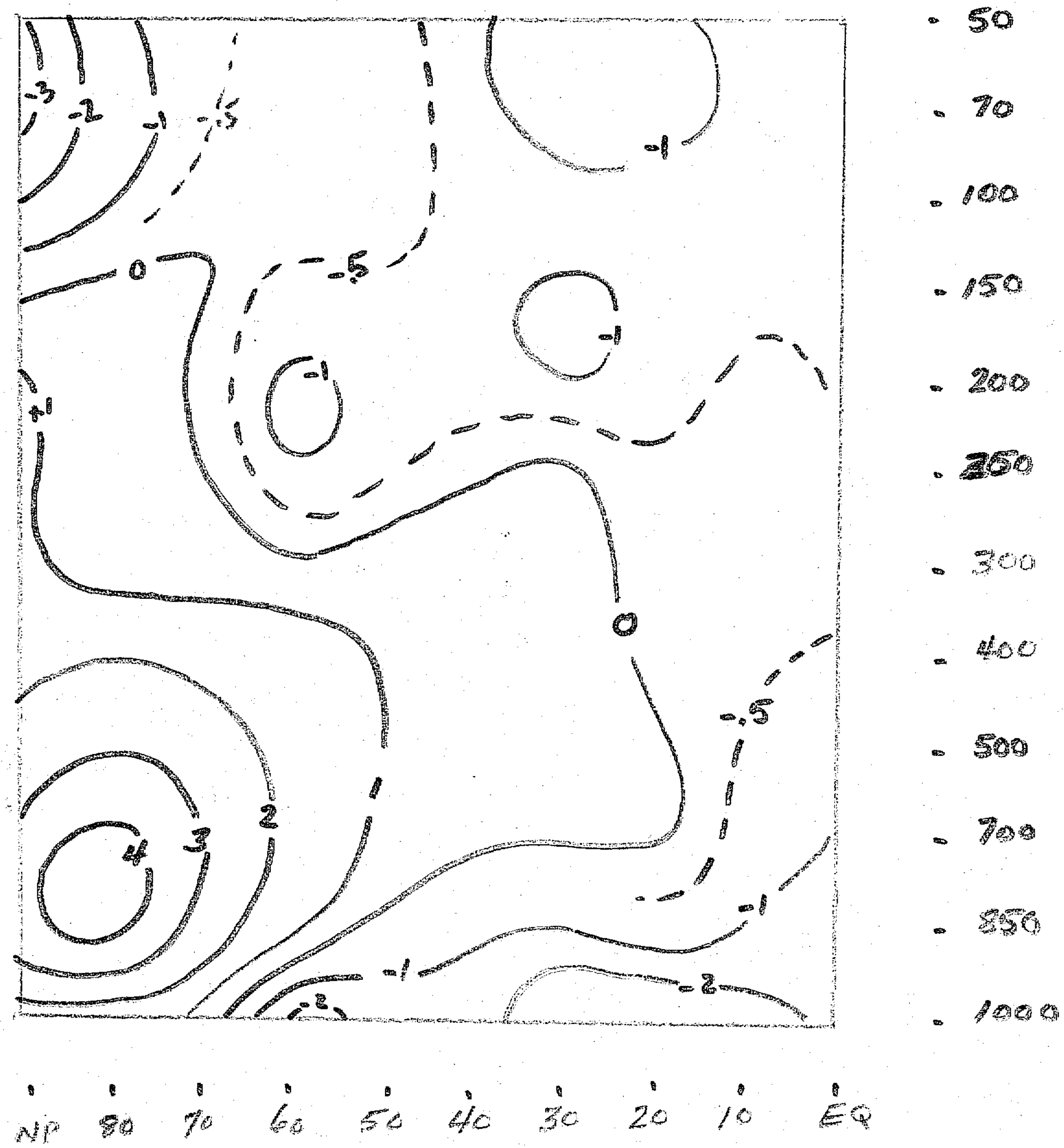
FEB 82

Fig 17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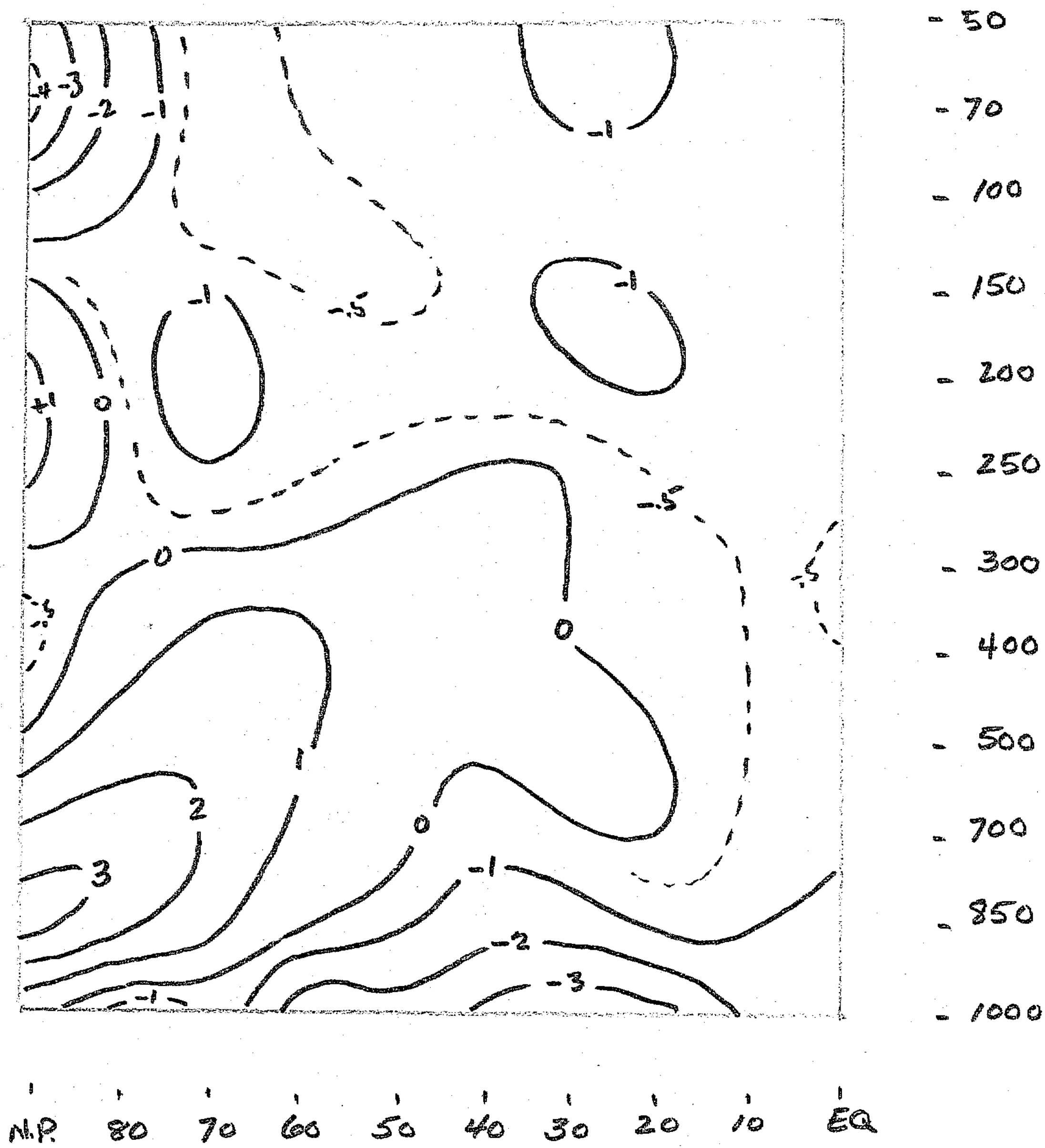
MAR 82

fig 18



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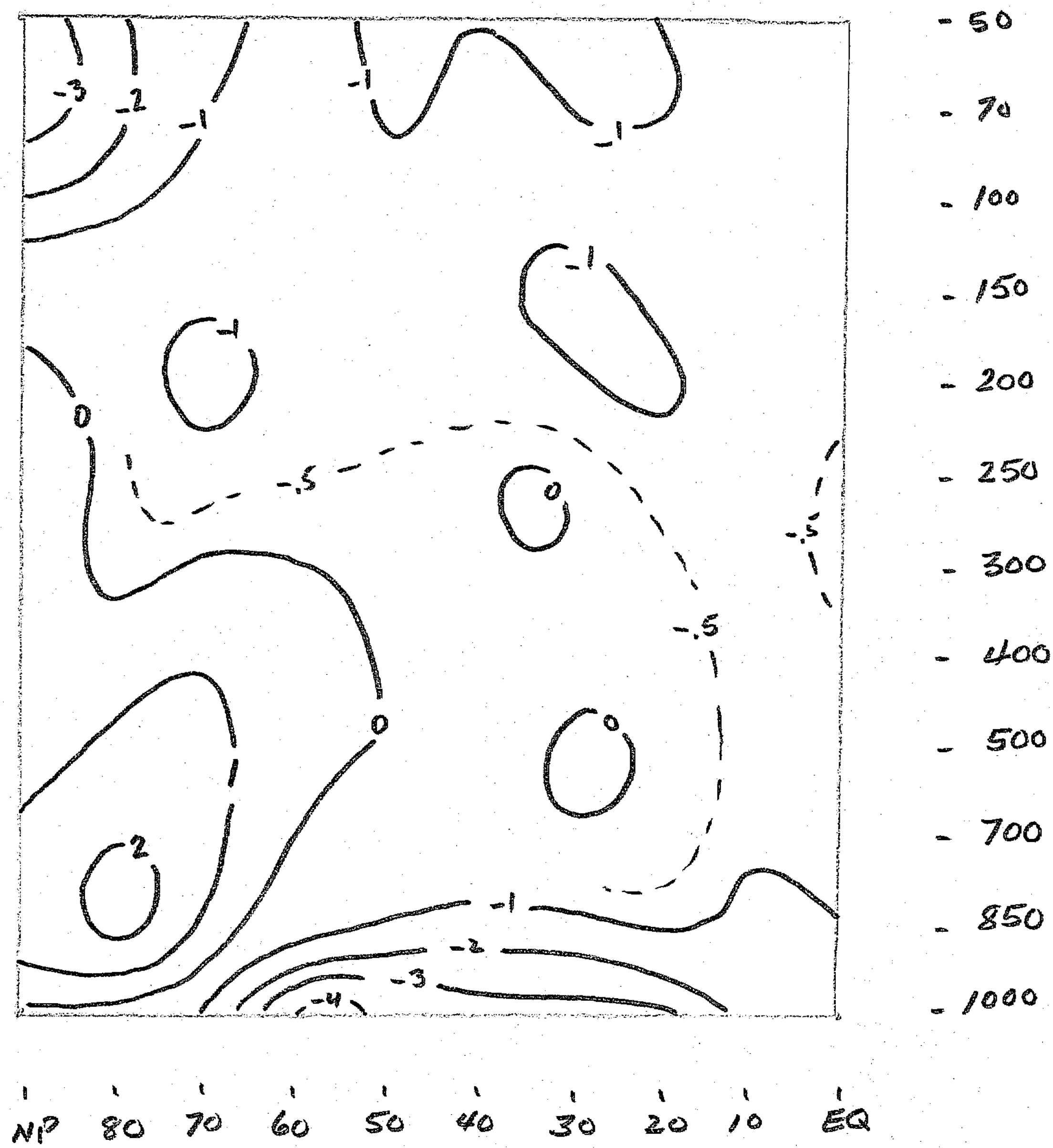
APR 82

Fig 19



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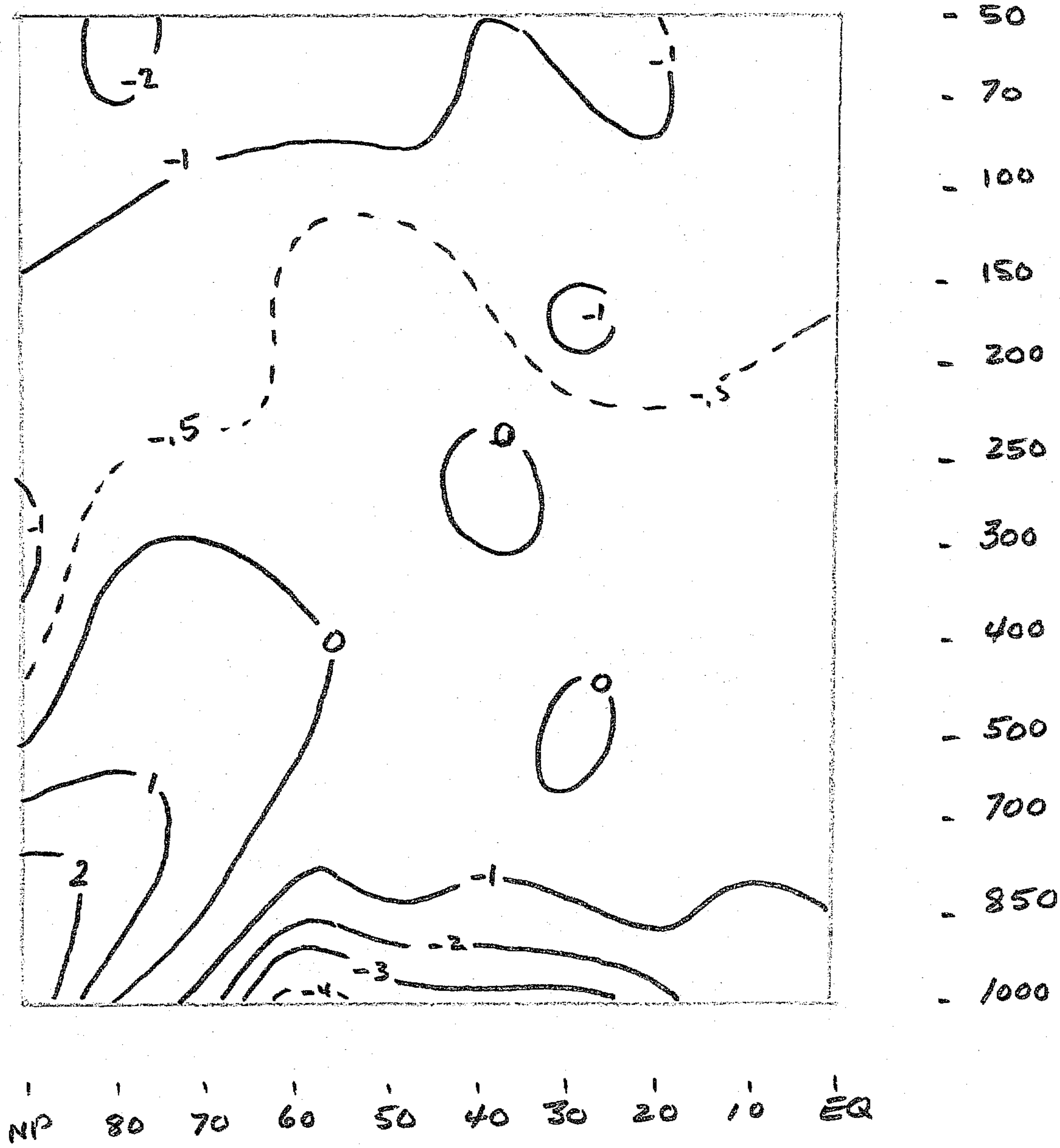
MAY 82

Fig 20



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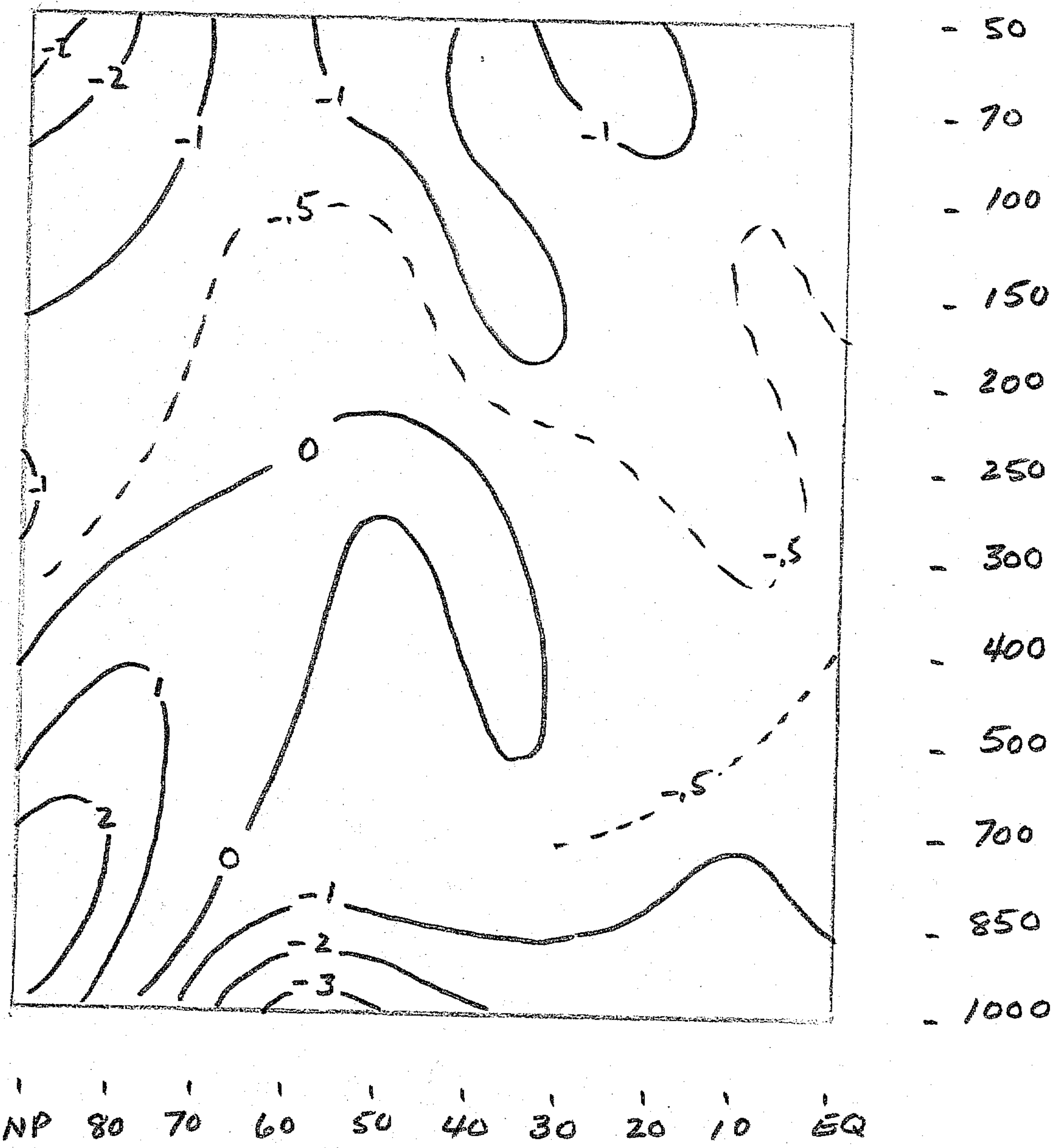
JUN 82

Fig 21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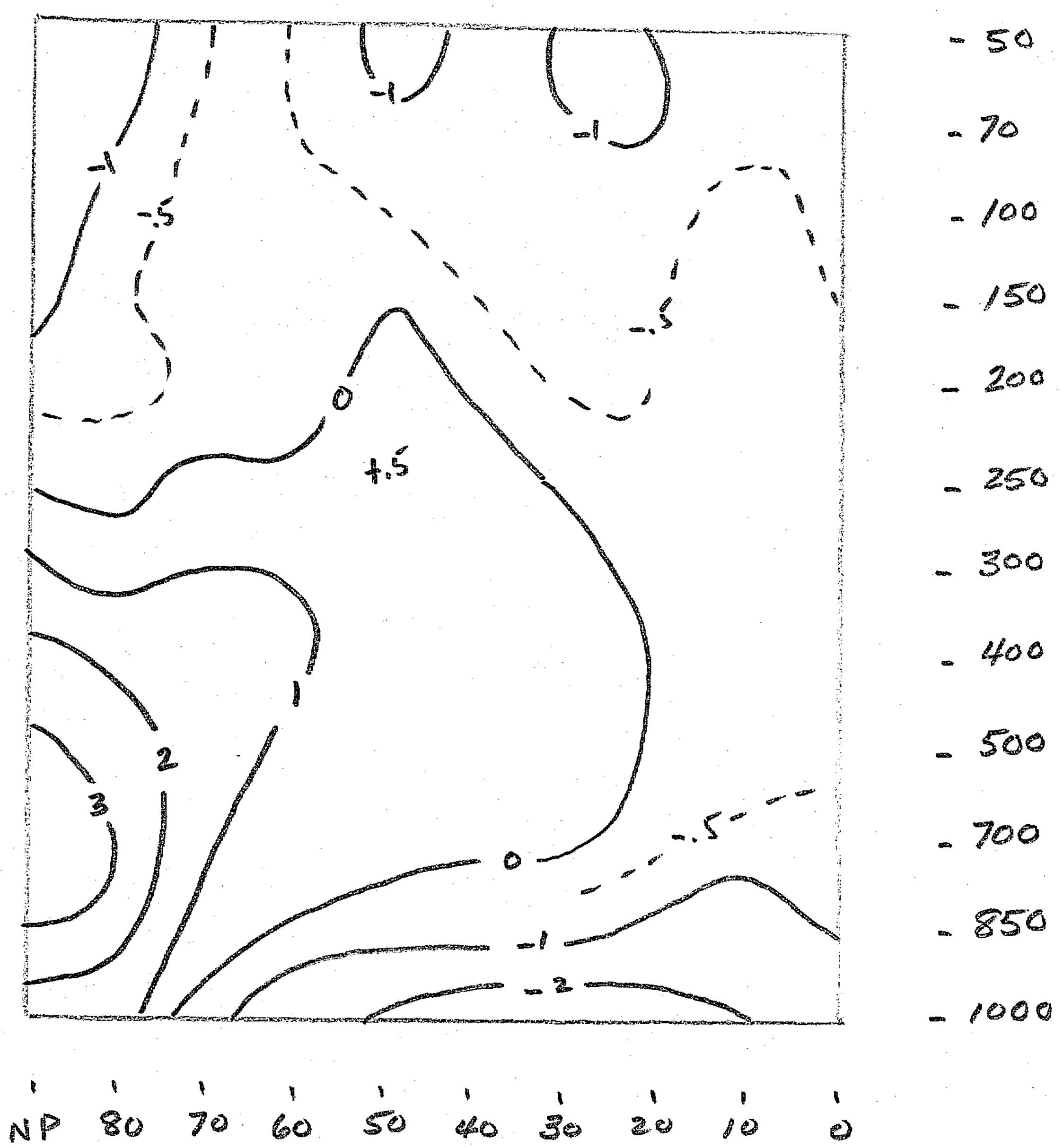
JUL 82

fig 22



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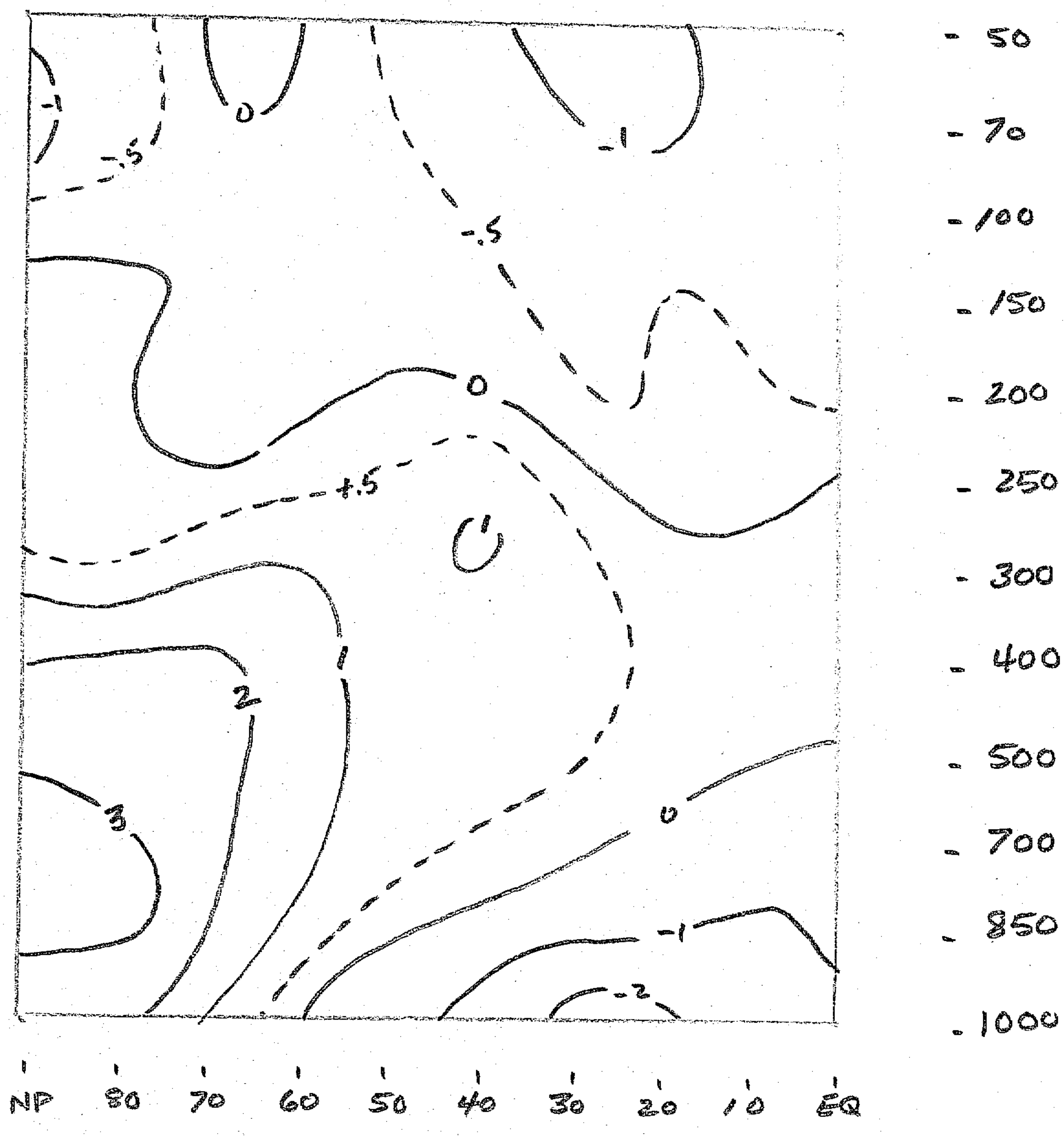
AUG 82

fig 23



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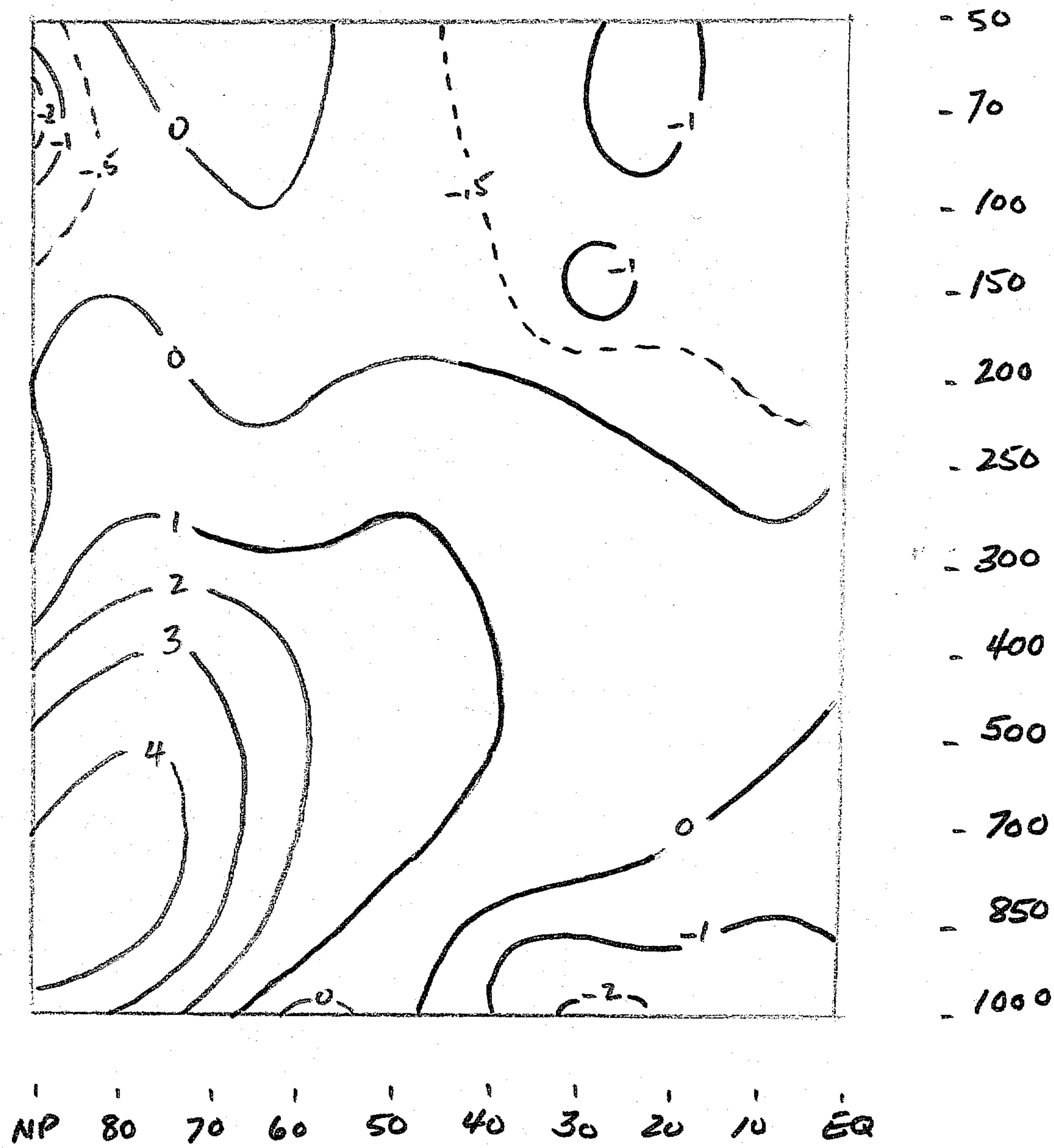
SEP 82

Fig 24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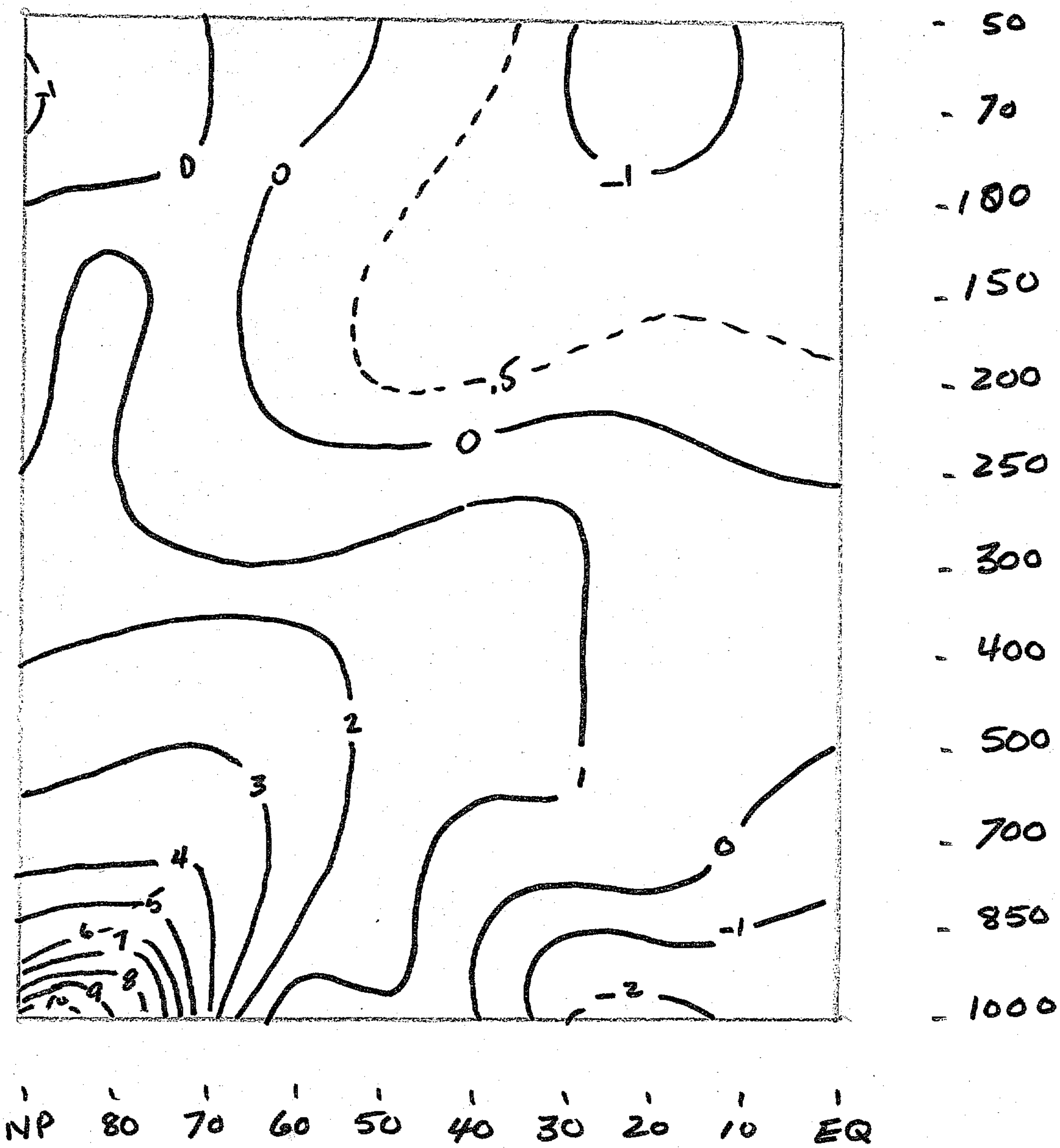
OCT 82

Fig 25



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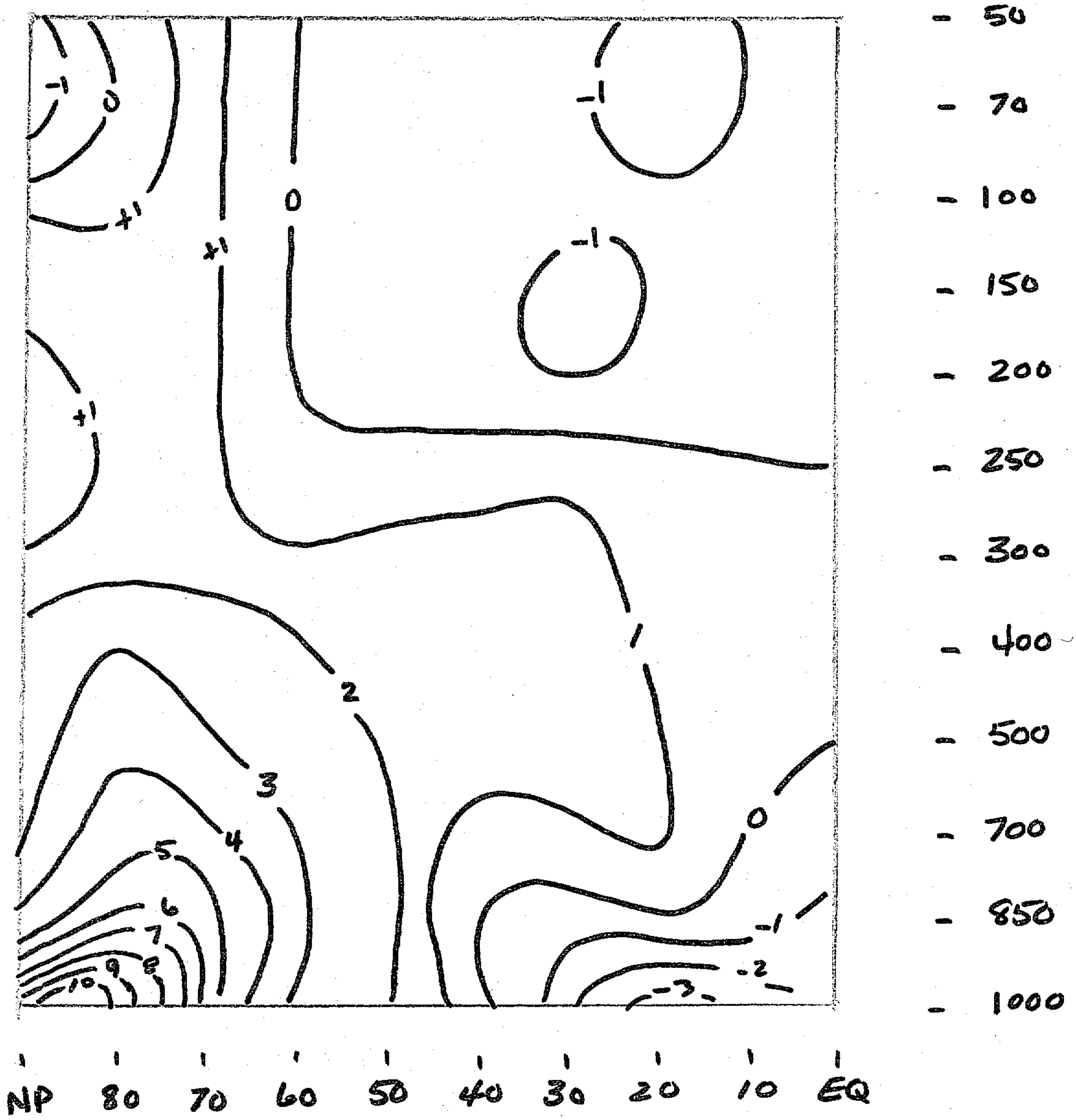
Nov 82

Fig 26



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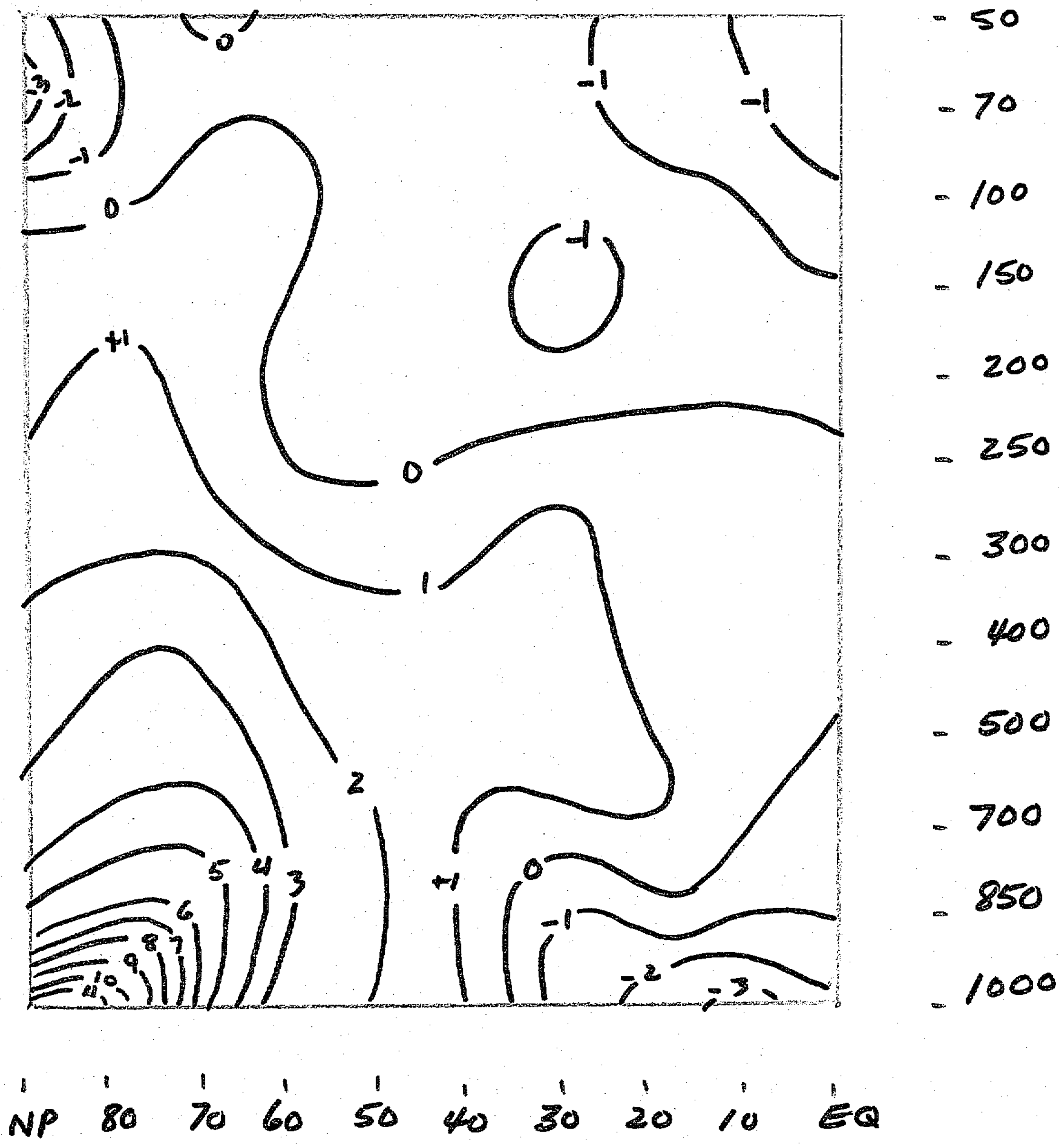
DEC 82

Fig 27



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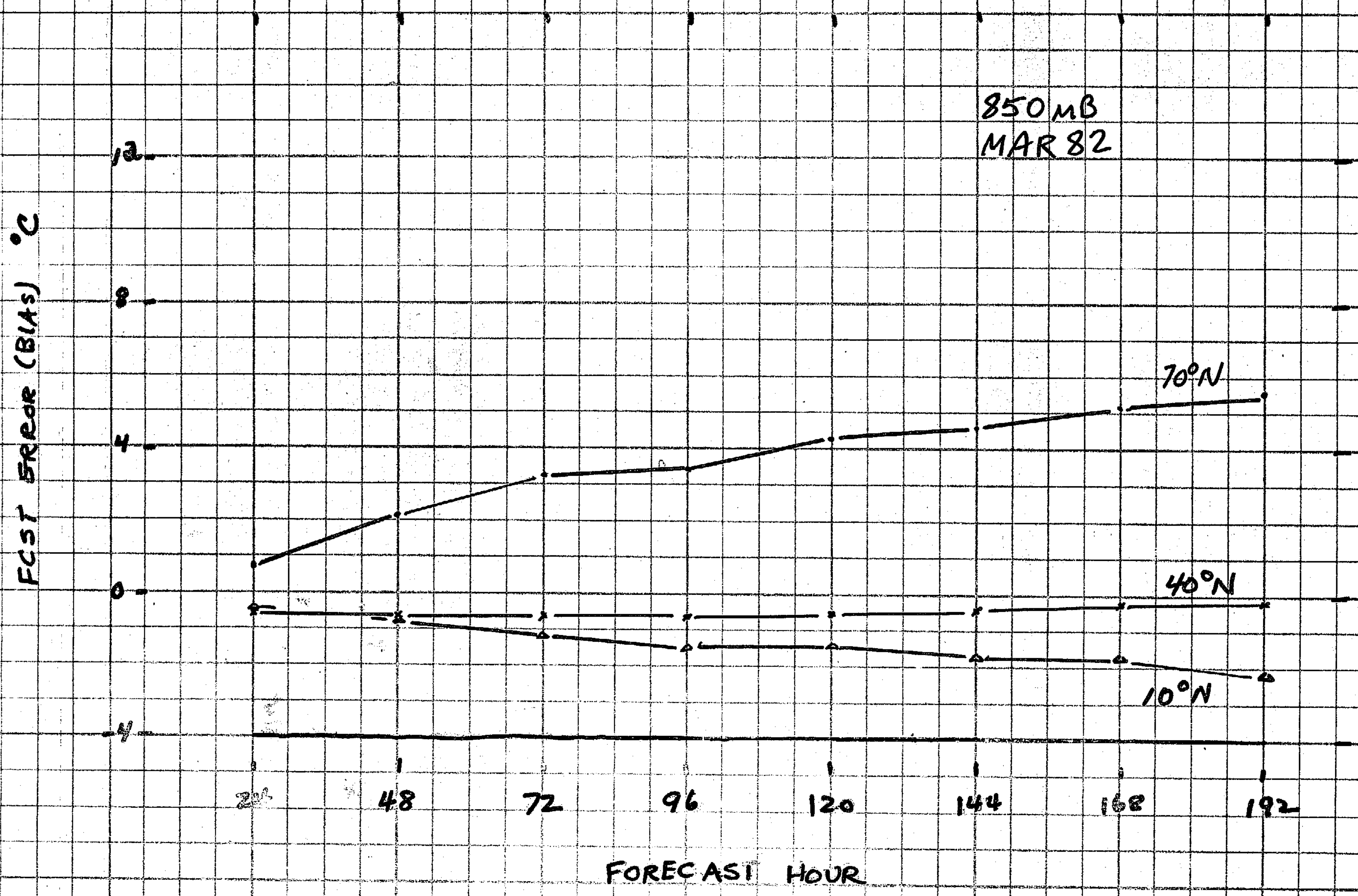
150
200
250
300
400
500
700
850
1000
NP
80
70
60
50
40
30
20
10
EQ

JAN 83

Fig 28


850 MB
MAR 82
FCST ERROR (BIAS) °C
12
8
4
0
-4
70°N
40°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR
Fig 29

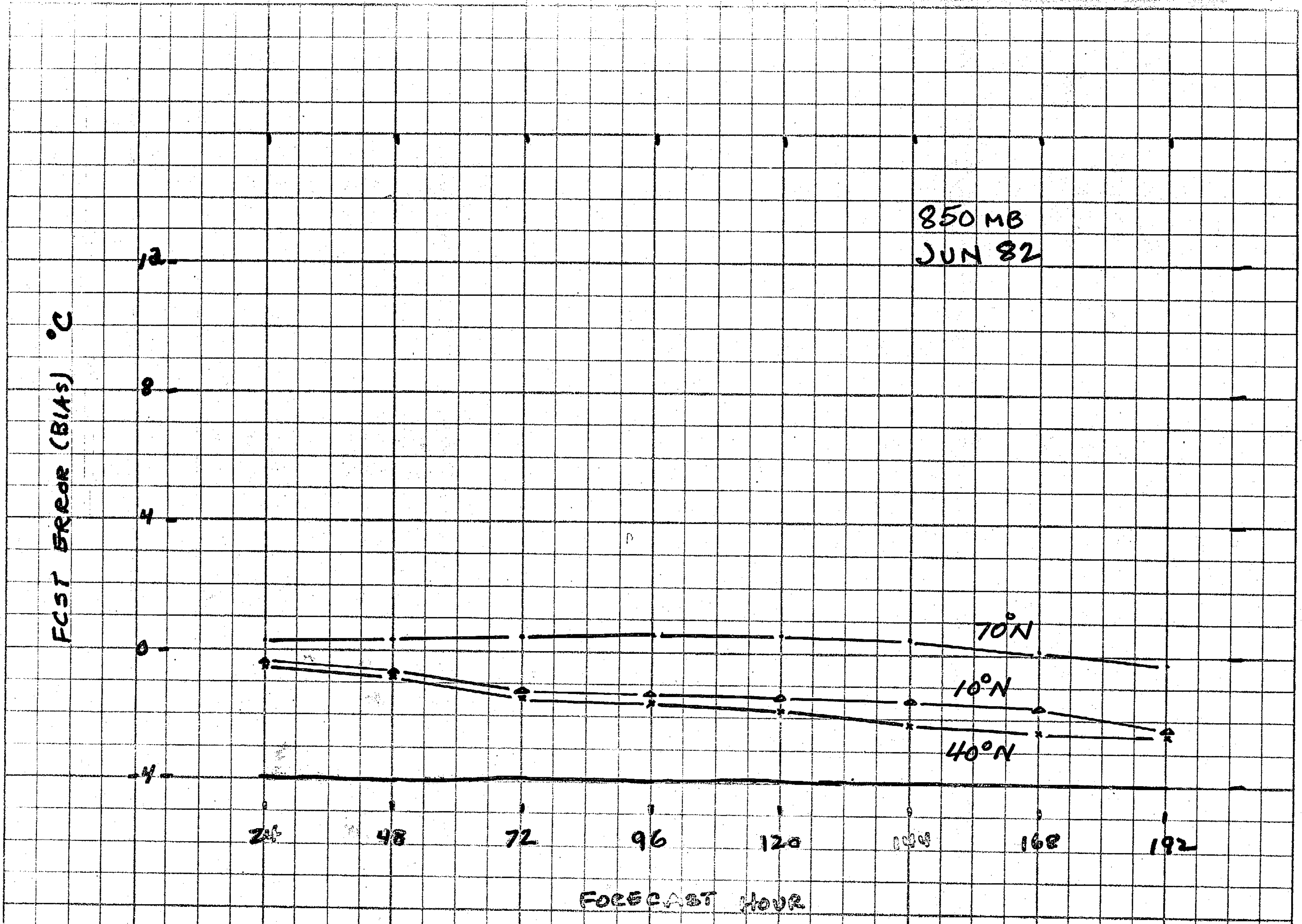
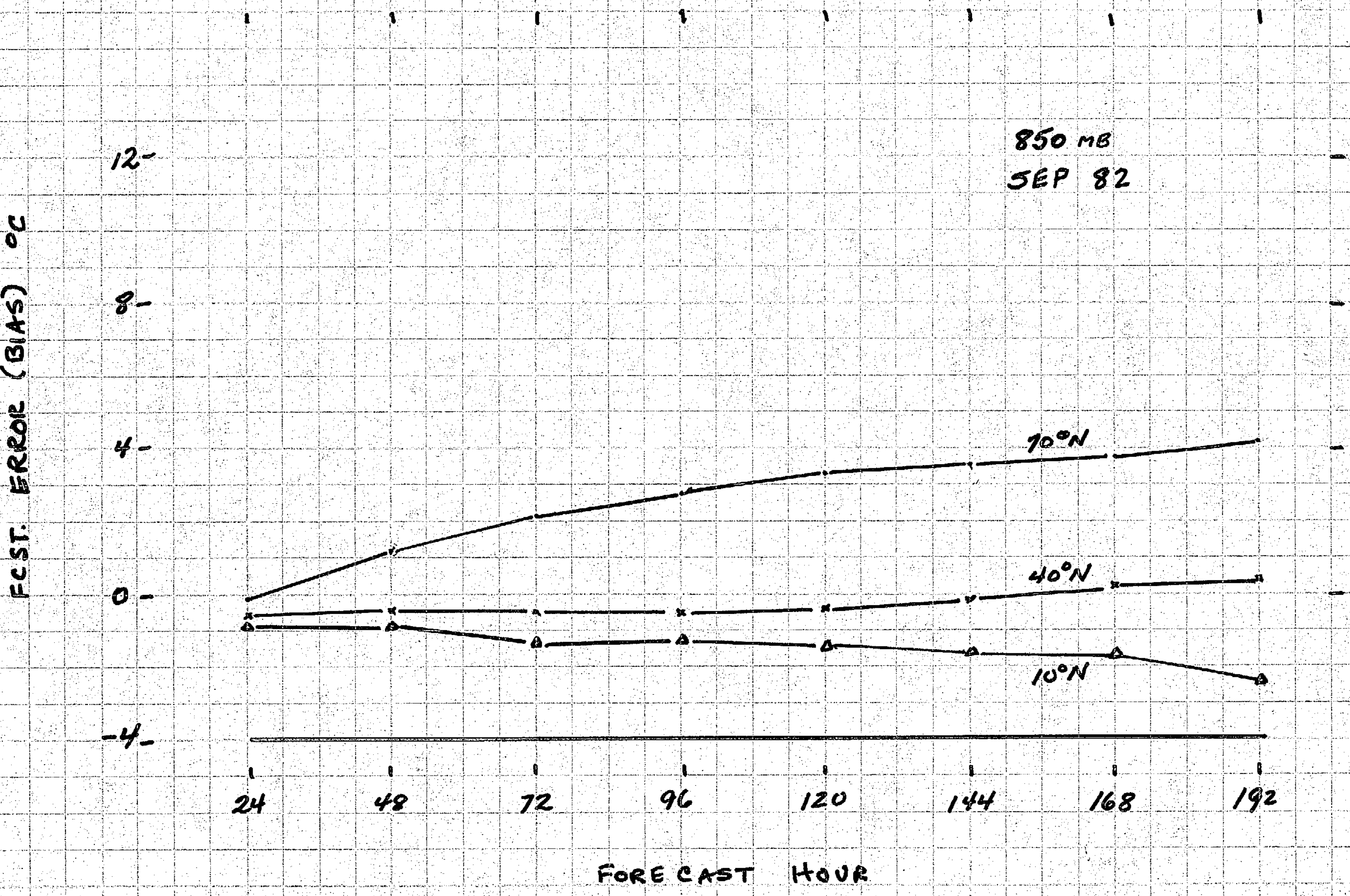


Fig 30

EUGENE DIETZGEN CO. NO. 377


850 MB
SEP 82
FCST. ERROR (BIAS) °C
12
8
4
0
-4
70°N
40°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR
Fig 31

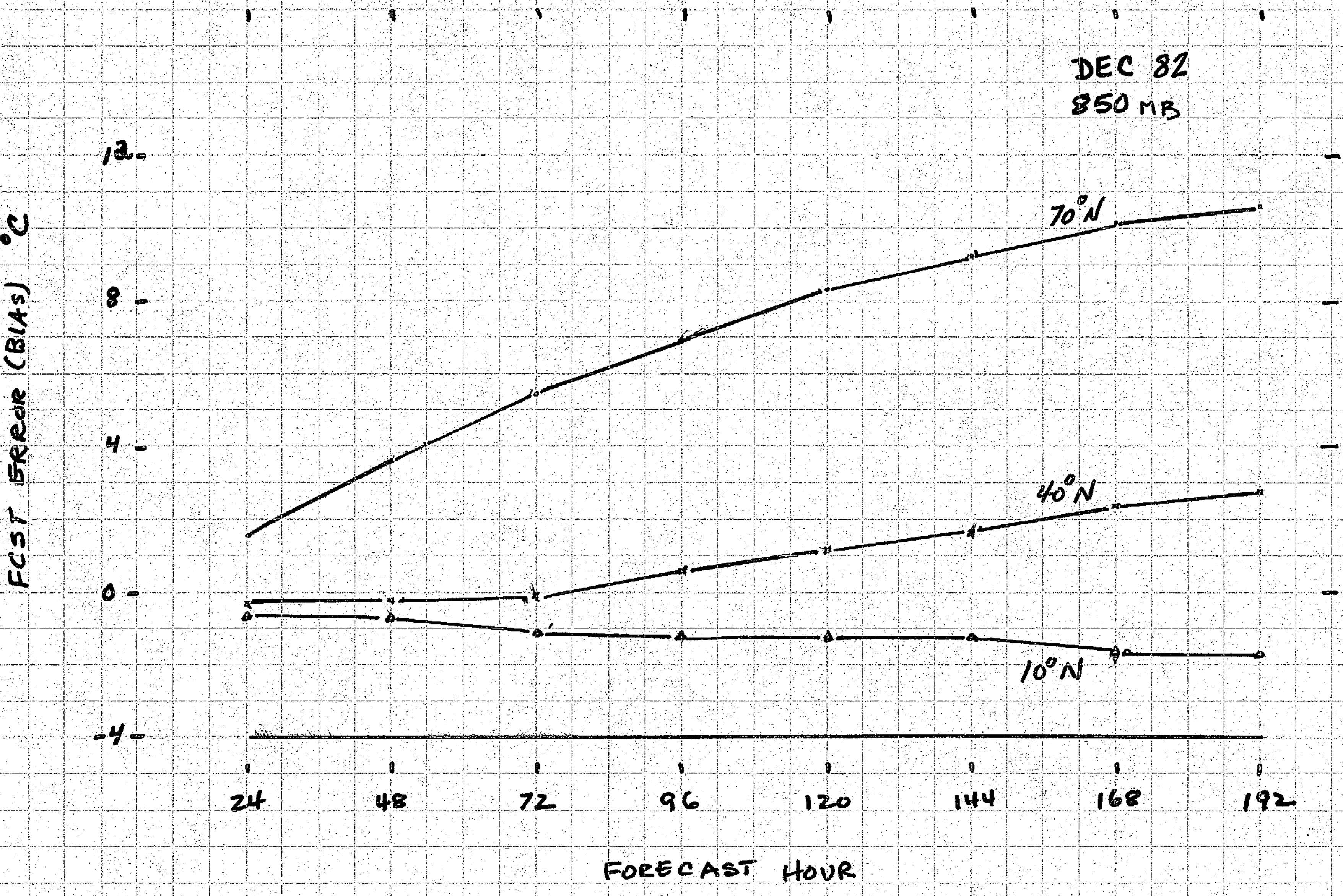

DEC 82
850 MB
12
8
4
0
-4
FCST ERROR (BIAS) °C
70°N
40°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR

fig 32

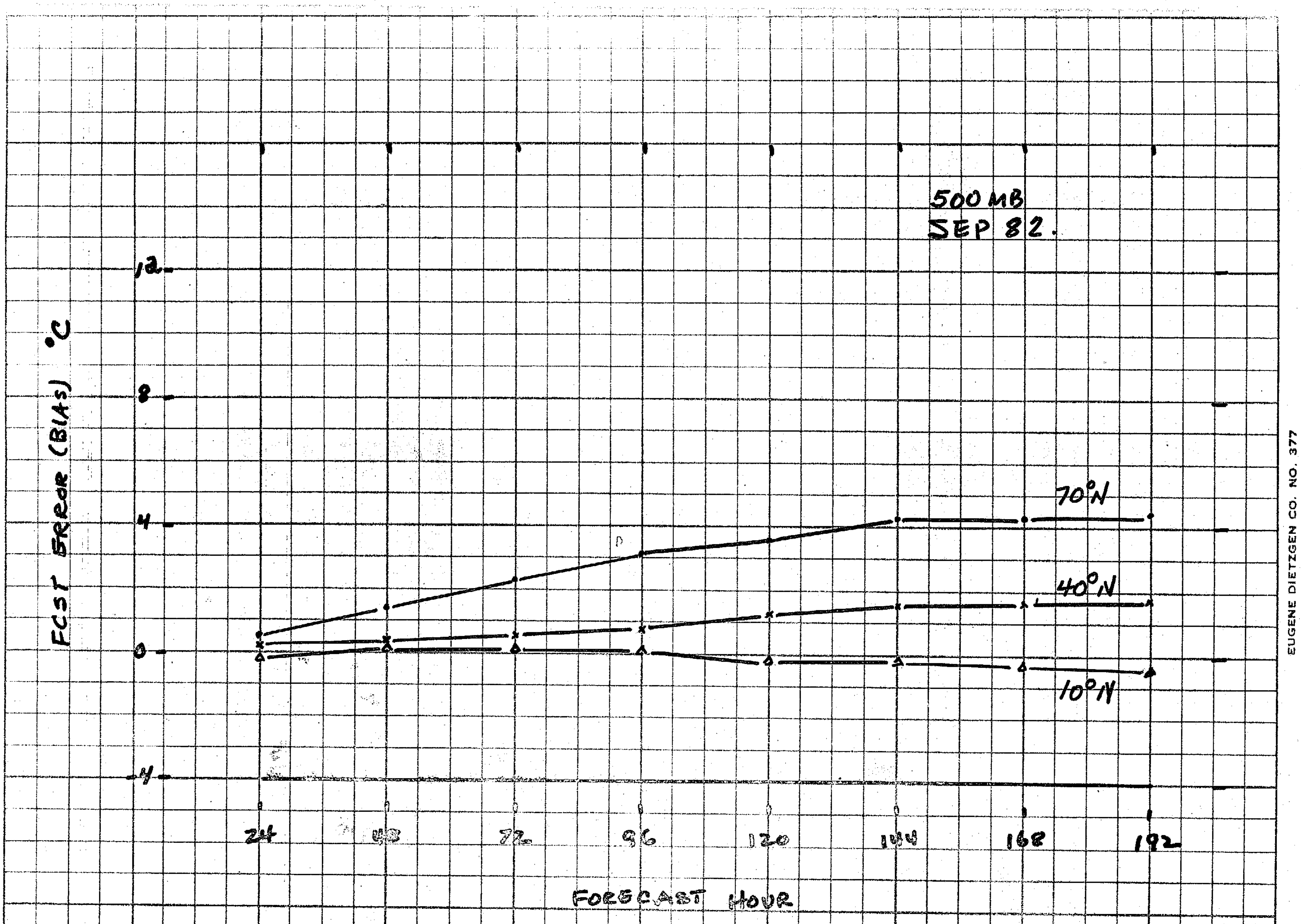

500 MB
SEP 82.
FCST ERROR (BIAS) °C
12
8
4
0
-4
70°N
40°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR
EUGENE DIETZGEN CO. NO. 377

Fig 33

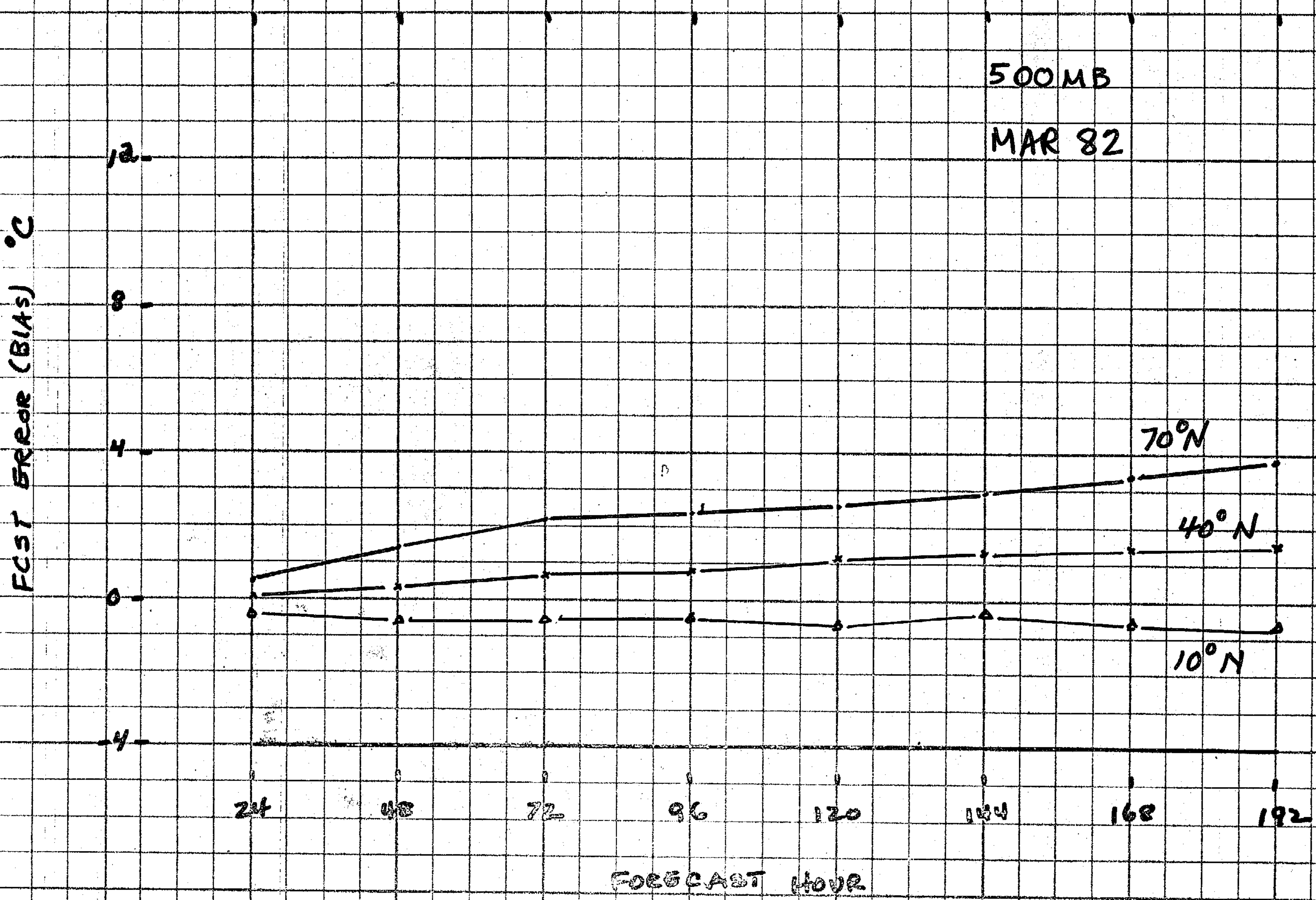


Fig 34

EUGENE DIETZGEN CO. NO. 377

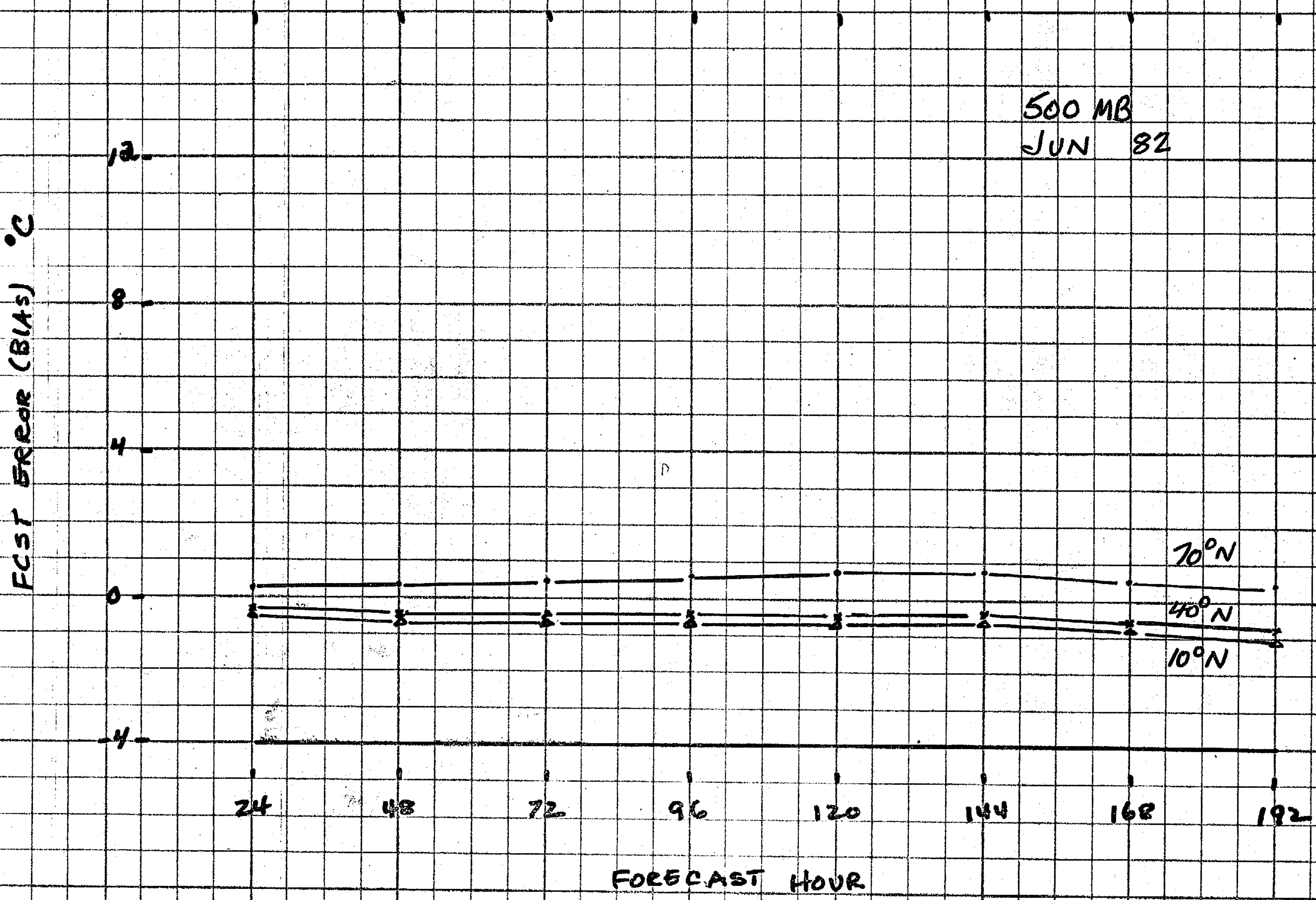


Fig 35

EUGENE DIETZGEN CO. NO. 377

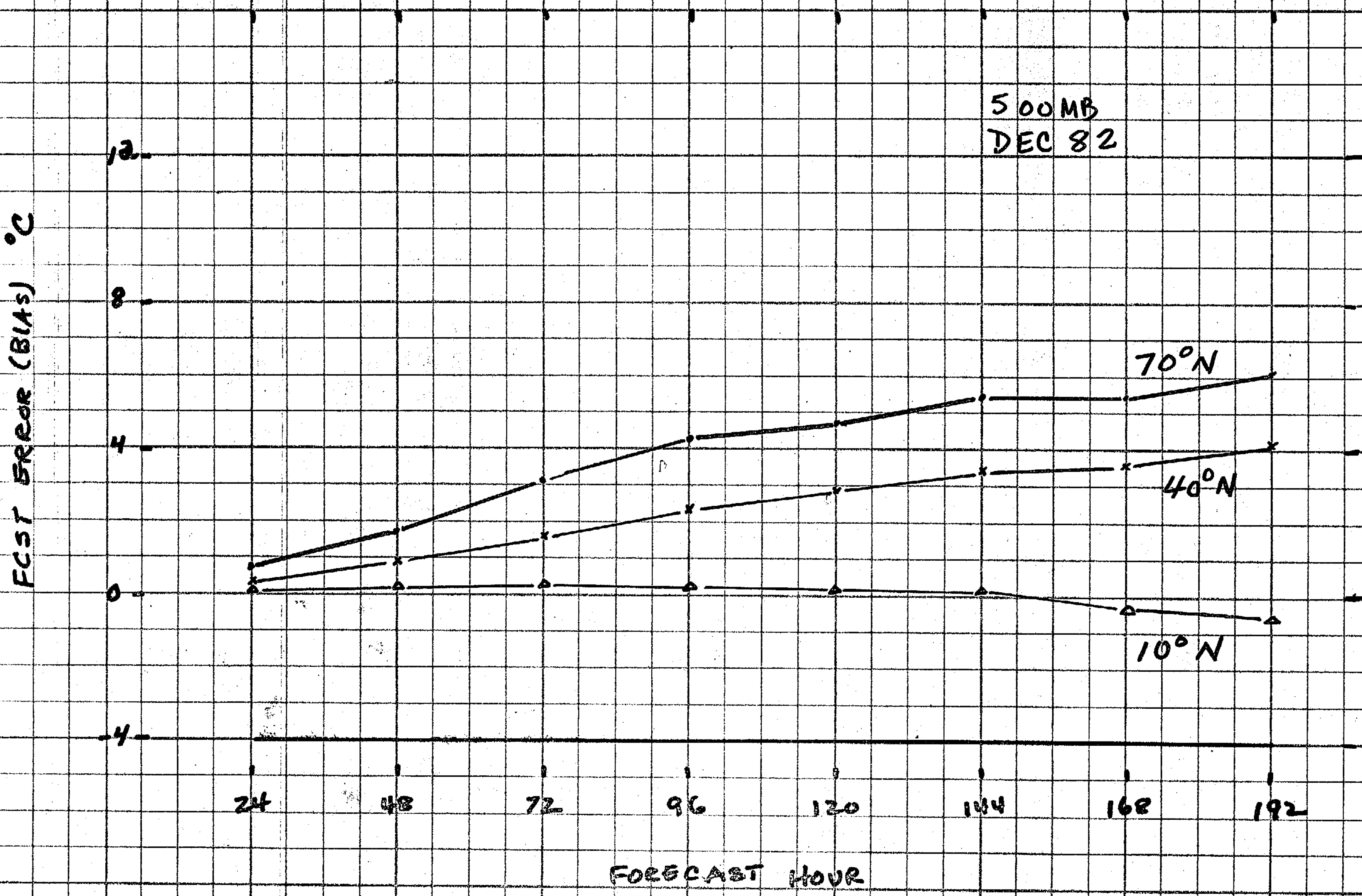
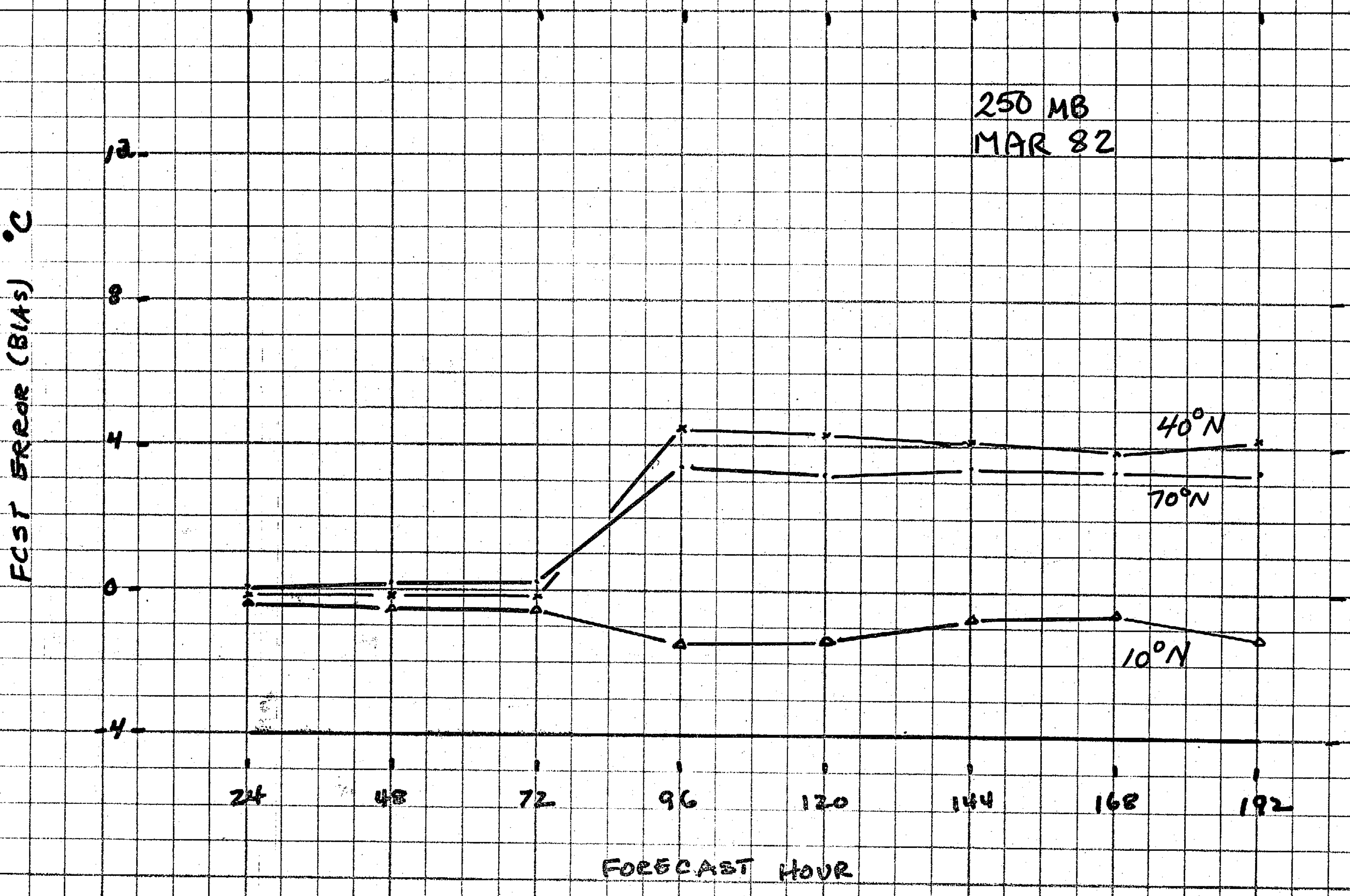


Fig 36

EUGENE DIETZGEN CO. NO. 377



250 MB
MAR 82
FCST ERROR (BIAS) °C
12
8
4
0
-4
40°N
70°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR

Fig 37

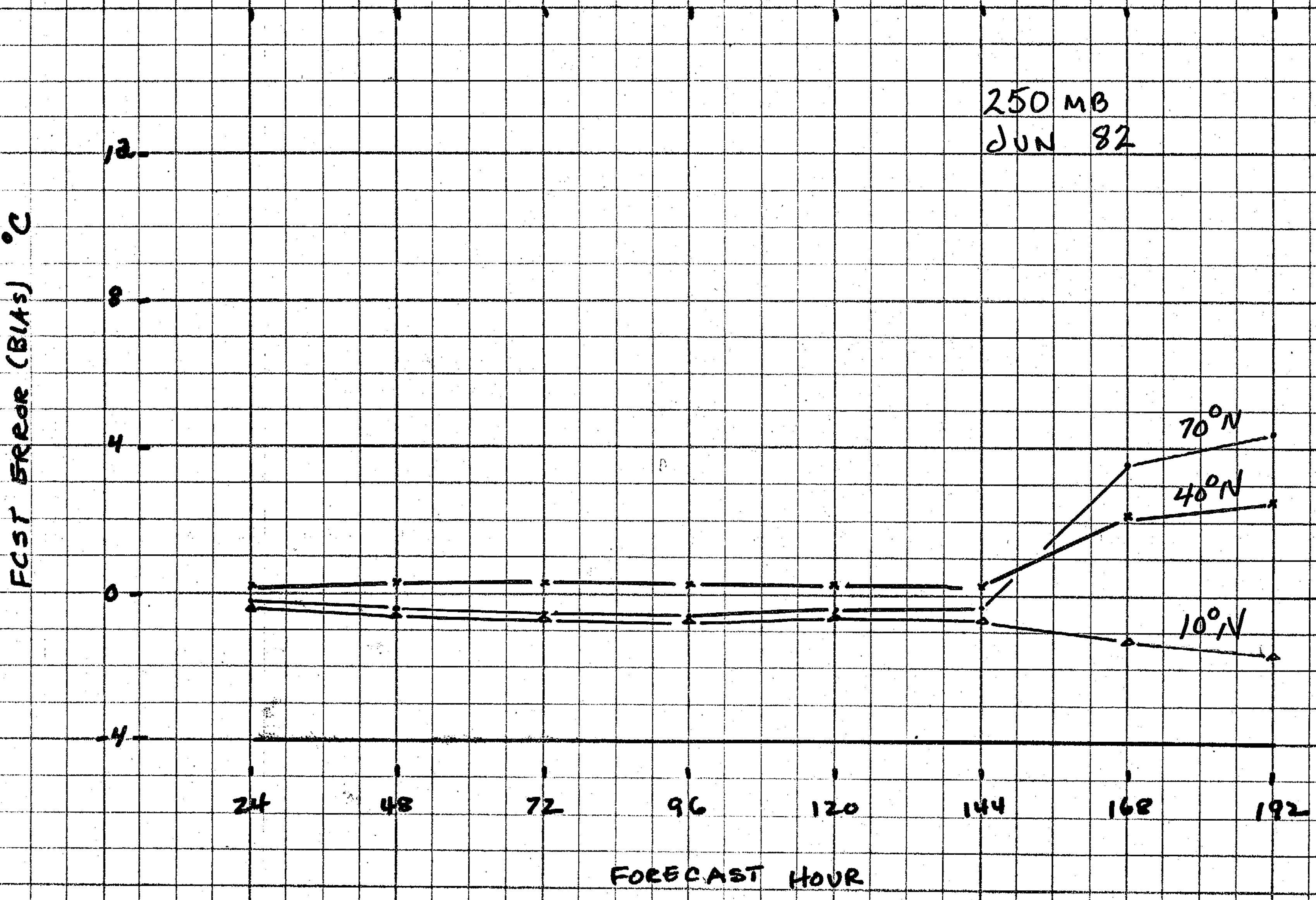


Fig 38

EUGENE DIETZGEN CO. NO. 377

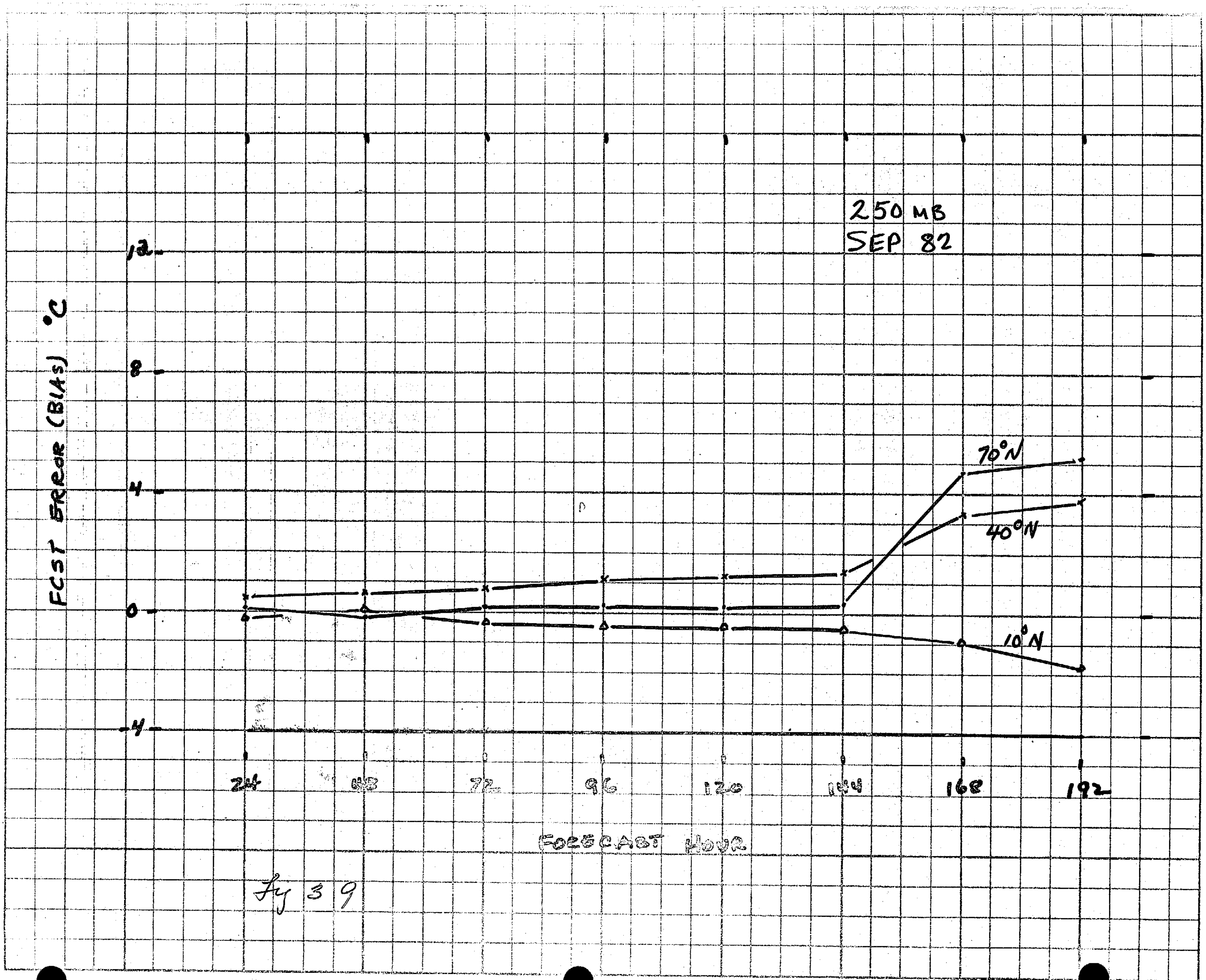

250 MB
SEP 82
FCST ERROR (BIAS) °C
12
8
4
0
-4
70°N
40°N
10°N
24
48
72
96
120
144
168
192
FORECAST HOUR

fig 39

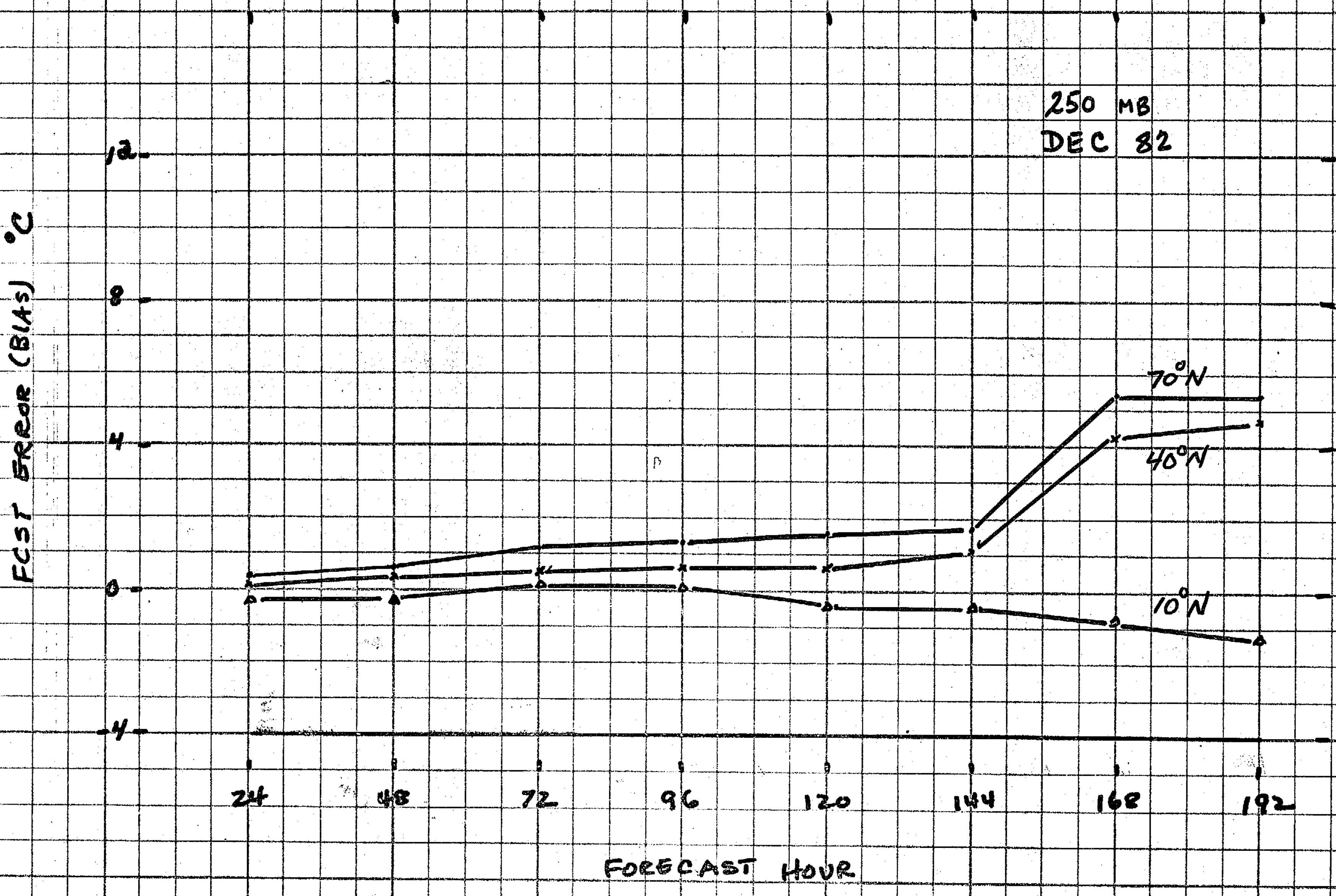


Fig 4a

EUGENE DIETZGEN CO. NO. 377